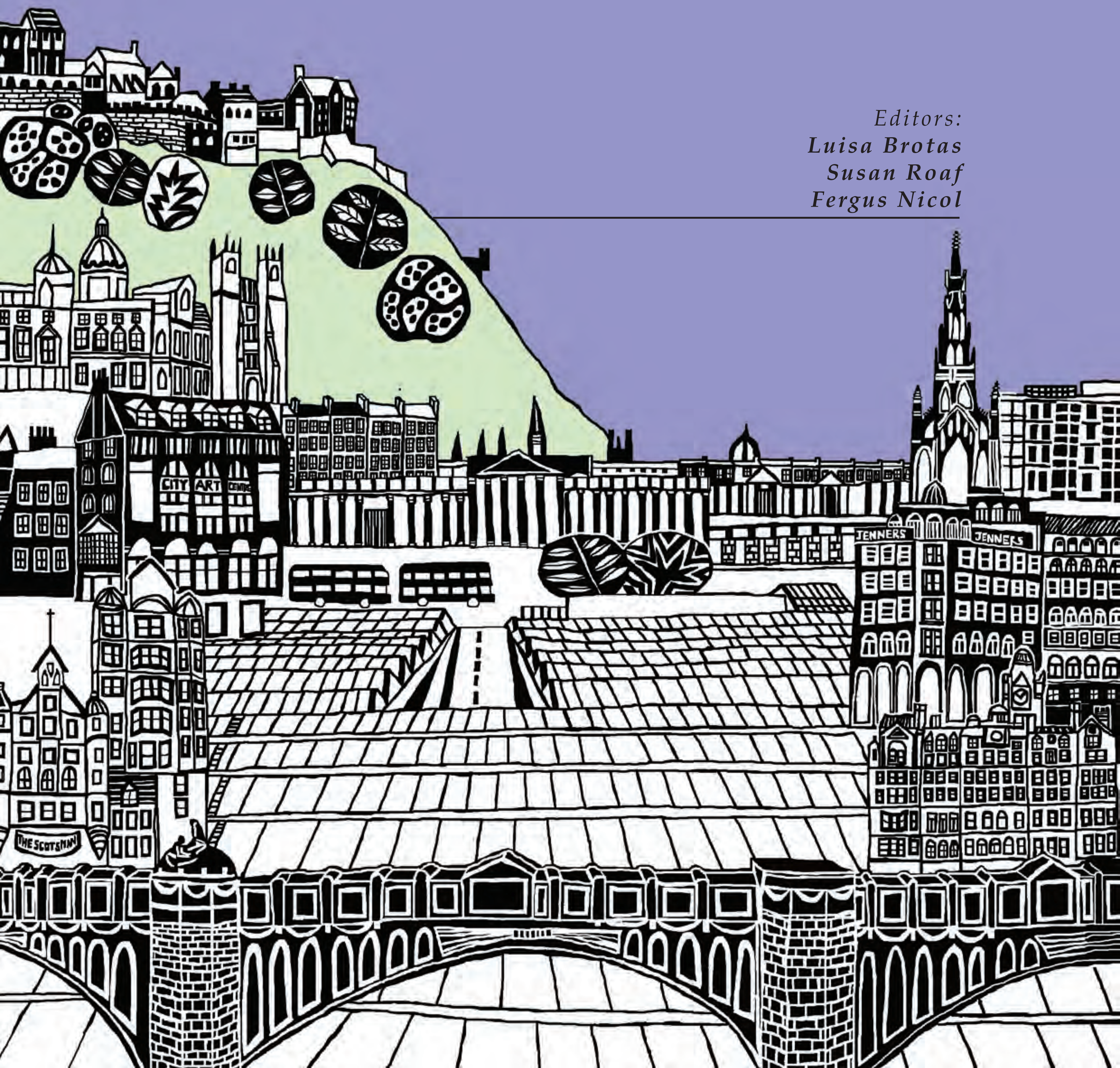
DESIGN TO THRIVE

Proceedings
Volume III

PLEA 2017 Conference



Editors:
Luisa Brotas
Susan Roaf
Fergus Nicol

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Introduction to the Proceedings of PLEA 2017

The question we all too often forget to ask is Why? Why, for instance did we in Edinburgh set out on the PLEA 2017 journey to give ourselves all the very hard work of creating a huge conference in which people from all over the world were invited to discuss and develop ideas of Passive and Low Energy Buildings (PLEA)? Well the answer is that we believe the issue of good building design, embraced for thirty five years by the PLEA movement is simply one of the most important there is in the evolution of a safer world in which people will be able to live comfortable and affordable lives in a rapidly changing world.

The PLEA organisation started in 1982 as a small group of international friends dedicated to the ideal of sharing knowledge on how to design and operate minimal and renewable energy buildings. The development of solar buildings lay at the core of its ethos in those early days and still does. PLEA now has a membership of several thousand professionals, academics and students from over forty countries (www.plea-arch.org). Having expected three to five hundred abstracts for the 2017 PLEA conference we were overwhelmed by more than fourteen hundred.

It is obvious that the time for PLEA thinking has come.

Where better to share these important ideas than in Edinburgh, the 18th Century capital of the European 'Age of Enlightenment'? It is here we set about creating our Team Scotland to organise the conference, held on the 2nd – 5th July 2017 and including 665 papers published in these Proceedings. The impressive list of people who helped us included: the Scottish schools of architecture and engineering, the City of Edinburgh, the Scottish Government, Historic Environment Scotland, the Royal Incorporation of Architects in Scotland, the Chartered Institution of Building Services Engineers and a host of related professional companies and organisations.

Reflecting the diverse interests of the team involved, the subject matter of the conference is separated in the following proceedings into papers sorted according to the thirty-one Forums in which they were presented at the conference. Readers should first review the contents lists to see which subject areas are of particular interest to them and then browse through the varied papers by selected Forums. Separation of the papers into these various fields enabled authors to present their ideas at the conference to smaller groups with whom they could expertly explore and discuss their own results while learning from other related studies that might lend light to their own thinking.

Introduction to the Proceedings of PLEA 2017

In discussions at one of our Forum Leader meetings we decided that in reality many of the the larger challenges we face could be distilled down into five different themes:

- Building Better, Safer Places for All (inclusion and resilience)
- Designing to Thrive in a Changing world (affordability and well-being in good buildings)
- Learning from, and building on, the Lessons of the Past (evidence based design evolution)
- Powering our Lives with Sustainable Energy (clear, durable and affordable futures)
- Empowering Current Generations (Education for change)

These themes run through in the pages of these proceedings, and were accompanied at the conference itself by a fascinating exchange of ideas, interpretations and assumptions and their attendant design solutions.

The conference was also accompanied by a simple Enlightenment message, presented in four flanking banners in the Ballroom of the Assembly Rooms where generations have deliberated since it was first opened at the height of the original Age of Enlightenmenttwo hundred and thirty ago:

Sun – Light – Wind – Natural Energy Buildings

The Editors:
Luisa Brotas
Sue Roaf
Fergus Nicol

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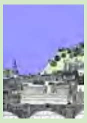

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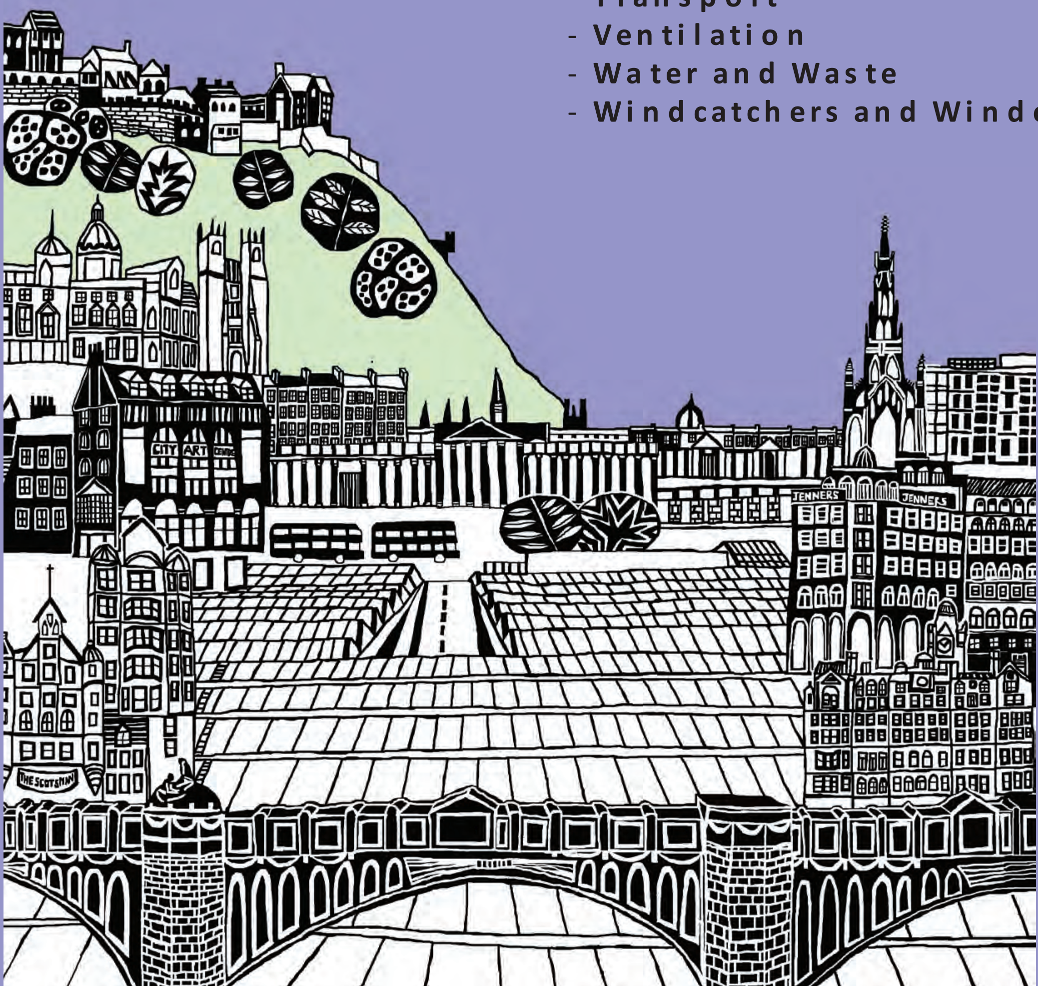

Low Carbon Design

PLEA 2017 Conference

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Thermal assessment of different configurations of roof ponds for passive cooling

José Manuel Almodóvar[1], Pablo La Roche[2] and Dongwoo Yeom[3]

[1] School of Architecture, University of Seville, Spain, jmalmodovar@us.es
[2,3] College of Environmental Design, Cal Poly Pomona, Los Angeles, USA, pmlaroche@cpp.edu, dongwoo.yeom@gmail.com

Abstract: This paper discusses the cooling potential of two pond roof prototypes built and tested in a hot-dry climate with mild winters. The first roof consists of a pond covered with a floating insulating panel with a spray system above it that operates at night. The second roof is composed of a flat aluminum plate separated from the water by an air gap. At night, the temperature of the aluminum sheet falls below the temperature of the water, and therefore, the water vapor inside the roof condenses and falls by gravity. The potential cooling of a Water to Air Heat Exchanger (WAHE) has also been tested by connecting the cells with the ponds by a pipe through which the cell's air is re-circulated by a fan. We ran multiple series and compared the results to a control cell that had an energy code compliant insulated roof. Results demonstrate that both pod roof variants have higher cooling potential than the code compliant control cell. The best performance is obtained in the insulated roof with WAHE operating all time. In this case, the indoor temperature can be kept below 24 ºC even with ambient temperatures above 35 ºC.

Keywords: pond roof, passive cooling, physical testing – mockups, cooling with water

Introduction

The roof is the most exposed building envelope element to the sky, providing a broad range of possibilities for passive cooling purposes. The concept of a roof pond was introduced by Hay and Yellot (1978), with the "skytherm" system, in which the cooling effect was obtained by nocturnal radiation. Givoni (1994) evaluated the performance of using fixed shade or floating insulation roof pond systems under different climatic conditions. In the last years, considerable resources have gone into the study of pond roofs and several authors have summarized the state of the art of pond roof variants (Spanaki et al., 2011).

This paper discusses two covered pond roofs coupled directly (conductively) with the indoor space for a hot-dry climate with mild winters. Particularly, a roof pond with a floating insulating panel and spray system operating at night and a roof with a sealed flat aluminum plate separated from the water by an air gap. In addition, the effect of a WAHE system on the performance of the pond roofs has been evaluated. A fan re-circulates the indoor air through a WAHE placed inside the pre-cooled pond roof's water that acts as an intermediate sink absorbing and dissipating energy through to the outside air that is the final heat sink.

The WAHE system was patented by Richard Bourne and David Springer (Bourne & Springer, 1992). Although earth to air heat exchangers (EAHE) that use the ground for heat storage and dissipation is being used increasingly (Peretti et al., 2013), WAHE have some advantages compared to EAHE (La Roche et al., 2016). The water dissipates more easily the heat exchanged with the pipe than soil and water has a higher thermal capacity than earth.

Experimental setup

To evaluate the benefits of adopting the different pond roof configurations, test cells were built and monitored at the Lyle Center for Regenerative Studies in Cal Poly Pomona. It is located in a hot-dry climate with mild winters about 40 km east of Los Angeles, in southern California (Figure 1).

Figure 1. Left: pond roof with floating insulation and spray system. Center: pond roof with a sealed aluminum plate. Right: details of the roof with aluminum plate

The test cells are 1.35 m x 1.35 m x 1.35 m, facing south, slightly to the west. The walls of the test cells are 178 mm thick, with drywall on the inside, 5.08 cm x 10.16 cm (2” x 4”) studs with glass wool insulation, OSB board, XPS insulation board, and plywood on the outside. The floor of the cell is made of OSB board and XPS insulation board. The U-value of the wall and floor is 0.308 W/m^2K and 0.299 W/m^2K respectively. The walls were painted white to reduce the heat gains. A double glazed window (610 mm x 610 mm) was installed in the south wall, and was tested with and without shade. A 10.16 cm (4”) exhaust fan and intake flap was installed separately for the ventilation, and 89 mm plastic wheels were installed under the cell to adjust direction and location of the cells. We have evaluated the different roof pond configurations in test cells with identical floor and walls, and we have compared the results with a control cell covered by a code compliant insulated roof with a U-value of 0.055 W/m^2K.

Data loggers were installed in multiple locations in the test cells to monitor the dry bulb temperature, mean radiant temperature, and relative humidity. The sensors were Onset models U12-012, UX 120-006M, and TMC6-HD respectively. Figure 2 shows their location in the test cells.

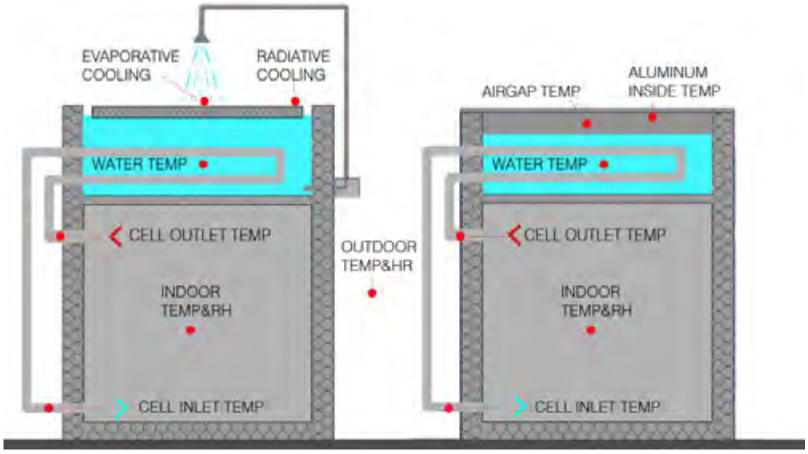

Figure 2. Sensors location

Experimental setup of the roof pond with floating insulation and sprayed at night

This roof is composed of a pond that is 0.35 m deep covered by a floating polystyrene insulation of 3 cm thick. A spray is placed over the pond roof to circulate the water over the insulation during the nighttime and, in turn, cool the water by radiation and evaporation (La Roche, 2012). The exterior surface of the insulating panel is white to reflect solar radiation and the paint provides some improvement in the re-radiation during the night. The spray is 0.5 m above the center of the water pond, the minimum height to provide some significant evaporative cooling (Yannas et al., 2000). The supporting roof is a metal deck that provides good thermal coupling with the space below. The U-value of the roof pond is 0.272 W/m^{2}K. The insulated roof pond was developed by Givoni and then tested with La Roche (La Roche and Givoni, 2000). The spray operation is limited to night hours (from 7 pm to 7 am) in order to improve efficiency and reduce the pond evaporation rate.

Experimental setup of the pond roof with an aluminum plate separated from the water by an air gap

This prototype is an evapo-reflective roof composed of a water pond of 20 cm deep covered with a flat aluminum plate separated from the water by and air gap of 10 cm. The system is properly sealed to prevent water vapor escaping outside. Therefore, no water waste by evaporation is produced. The upper surface of the aluminum sheet is painted white to enhance its reflective properties. At night, the temperature of the aluminum sheet falls below the temperature of the water, and therefore, the water vapor inside the roof condenses and falls by gravity. This way, heat is transferred outside the system. A previous dynamic mathematical model for other pond roof covered by an aluminum plate variant was developed for a hot and dry climate (Ben Cheikh and Bouchair, 2004). Subsequently, it was discussed and compared with other pond roofs by Sharifi and Yamagata (2015). The pond roof is supporting by a metal deck that provides good thermal coupling with the cell indoor air. The U-value is 1.311 W/m^{2}K.

Water to air heat exchanger (WAHE) system description

The cooled water of the pond roofs is used to cool the interior of the test cells by the use of a WAHE. A fan in the pipe connecting the test cells to the pond roofs circulates the indoor air of the experimental cells through a WAHE placed inside the pond's water. The air transfers heat by convection to the underwater pipe which exchanges by conduction heat with water. Finally, the pre-cooled air is introduced into the test cell to reduce overheating (Fig. 3).

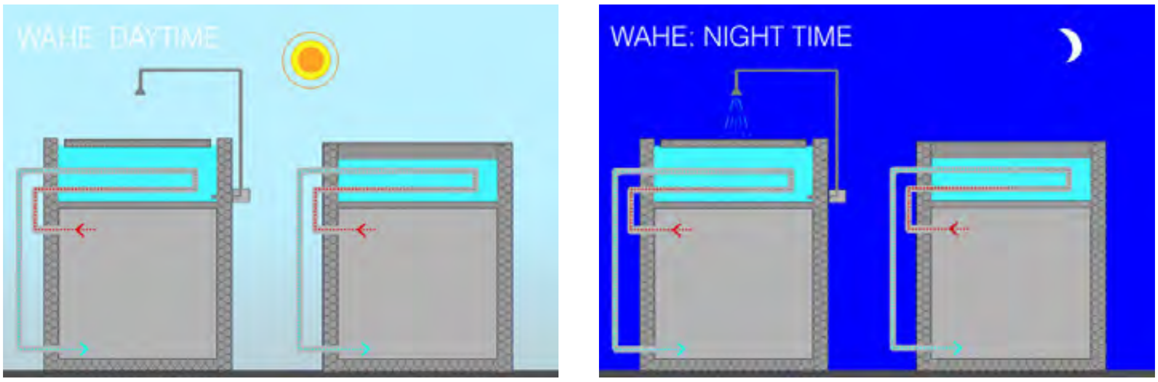

Figure 3. WAHE system operation

A PVC pipe wrapped with batt insulation, waterproofing and aluminum foil moves the air from inside the cells to the pond roofs. However, a flexible uninsulated aluminum pipe under the water increases the pipe's thermal conductivity and WAHE efficiency. Based in previous experimental evaluations for the dimensioning of WAHE in water ponds (Almodovar et al., 2016), we have selected an underwater aluminum pipe of 10.16 cm (4") diameter and 3.5 m length; 1.5 m/s flow velocity; and fan operating all the time (day and night) to continuously reduce the indoor air temperature.

Results

We ran multiple series from August to the beginning of October 2016 and compared the results of different pond roof configurations to a control cell that had a California energy code compliant insulated roof. Due to the space limitation only a few selected series are presented in this paper.

Results of the pond roof with a floating insulation and sprayed at night

Series 1 (Aug. 31 to Sep. 4)
The spray system operates at night (from 7 am to 7 pm) and the WAHE is not connected. The series evaluates the cooling effect of the night-time spray system above the insulating panel to cool the water by evaporation and radiation to the sky and also the effect in cooling the space coupled below by a metal plate.

Maximum temperatures are a good indicator of the cooling performance of the system. The higher the difference between the inside and outside maximum air temperature, assuming a lower temperature inside the test cell, the better the performance. Results show that even with outside temperatures above 35 ºC the cell air temperature can be kept below 27 ºC (8 ºC less than outside) while the control cell maximum temperature is around 29 ºC. Thus, the test cell has better performance than the control cell that reaches 2 ºC more (Fig. 4).

Series 2 (Aug. 21 to 26)
This series investigates the same roof configuration than series 1 but with the WAHE system operating all time (day and night). The results report that the system's performance is far better. The maximum indoor temperature is below 24 ºC while the ambient temperature is around 35 ºC. Hence, a difference of more than 10 ºC is recorded (Fig. 4).

The difference between the maximum pre-cooled air temperature at the pond outlet and the maximum water temperature is only around 1 ºC, while the rate of evaporation was 3.5 mm/day (so around 6.3 liters evaporated per day). On the other hand, results show that the air temperature is almost identical in the cell outlet and pond inlet, as well as the pond outlet and cell inlet. Therefore, the heat transfer when the air circulates through the pipes connecting the interior of the cell and the pond water is negligible.

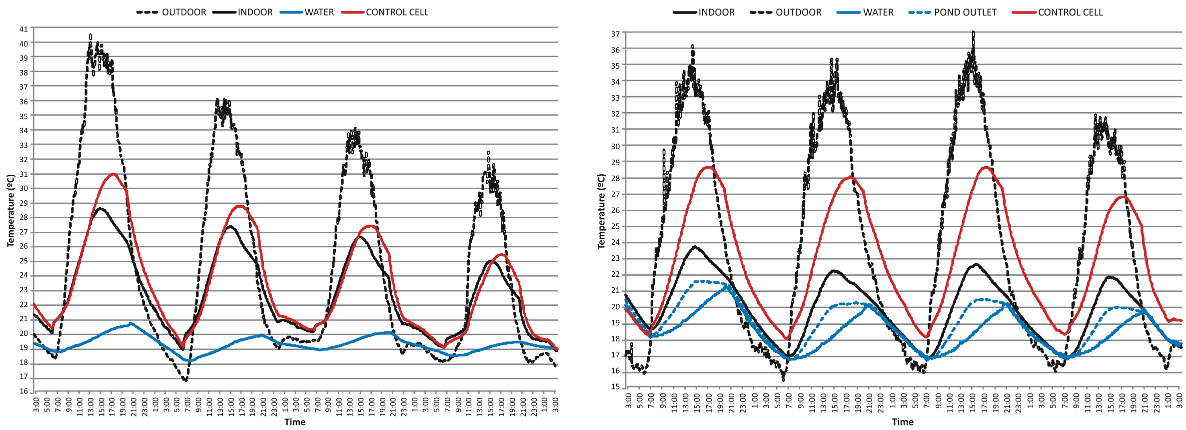

Figure 4. Temperature measured in the insulated pond roof with sprays working at night. Left: series 1, without WAHE. Right: series 2, with WAHE

Results of the pond roof with an aluminum plate separated from the water by an air gap

Series 3 (July 26 to 31)

The WAHE do not operate. Results show that the maximum water temperature is slightly higher than the insulated pond roof with sprays at night. However, the difference between the maximum outdoor and indoor temperature is still high, more than 6 ºC when the ambient temperature reaches 35 ºC. Moreover, the test cell performance is also better than the control cell, being its maximum temperature around 1 ºC lower (Fig. 5).

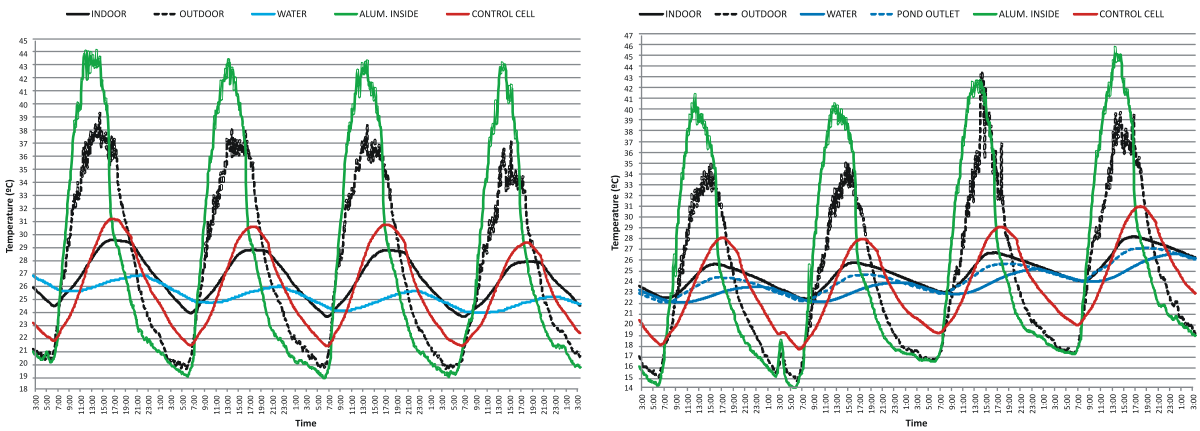

Figure 5. Temperature measured in the aluminum roof. Left: series 3, no WAHE. Right: series 4, with WAHE

Series 4 (Aug. 9 to 14)

This series is similar to series 3 but with the WAHE system operating all day. The test cell maximum indoor temperature can be kept more than 2 ºC below the control cell and the difference between the indoor and outdoor maximum temperature is more than 8 ºC when ambient temperature is over 35 ºC. Therefore, the WAHE considerably increases the cooling performance of the pond roof. On the other hand, the heat exchange in the WAHE is as efficient as in series 2. The difference between the maximum pre-cooled air temperature and the water is only around 1 ºC (Fig. 5).

Series 5 (Aug. 14 to 19)

We tested the same system that in series 4 but with a spray system placed over the water (below the aluminum sheet) that operates at night (from 7 pm to 7 am). Results show the cooling potential is lower than in series 4 (without sprays). When sprays operate at night the aluminum inner surface temperature increases an average of around 6 ºC, from a value close to the outside temperature to about 1 ºC below the water temperature. Due to the higher aluminum inner surface temperature, the condensation process decreases and then also the cooling performance of the whole system (Fig. 6).

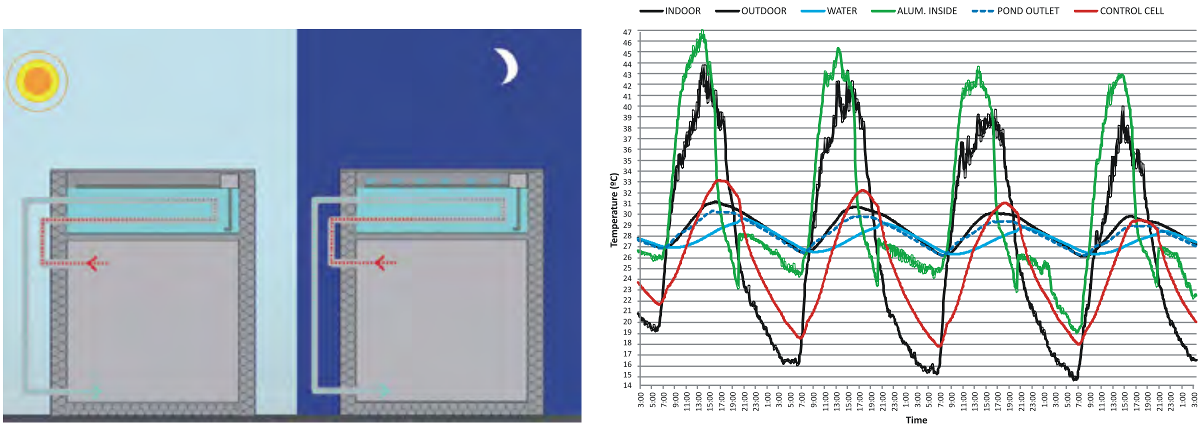

Figure 6. Temperature measured in series 5. Pond roof with aluminum plate, WAHE and spray system

Temperature Difference Ratio (TDR)

The temperature difference ratio (TDR) was proposed by Givoni and implemented by La Roche (2011) and used with good results to compare passive cooling systems with different configurations. TDR is determined by comparing the average reduction of the maximum temperature inside the cell with the average swing as expressed in the following equation:

$$TDR = (T_{max\text{-}out} - T_{max\text{-}in}) / (T_{max\text{-}out} - T_{min\text{-}out}) \quad (1)$$

Where: $T_{max\text{-}out}$ = maximum temperature outside; $T_{max\text{-}in}$ = maximum temperature inside; $T_{min\text{-}out}$ = minimum temperature inside.

The numerator is the difference between the indoor maximum temperature and the outside maximum, and the denominator is the outdoor swing. A higher value indicates that there is a larger temperature difference between outside and inside and there is more cooling. Using TDR we have compared results of the different pond roof configurations and the control cell as a function of the outdoor temperature swing.

Results show that the insulated roof with sprays + WAHE has the better performance, an average of 0.17 better than the roof covered with aluminum + WAHE and 0.23 than the control cell. The performance of the different pond roofs considerably decrease when the WAHE do not operate. More specifically, the insulated pond decreases around 0.12 and the pond roof covered with aluminum plate 0.04. Only the performance of the roof covered with aluminum with sprays working at night is worse than the control cell. Each point in figure 7 is one day’s data.

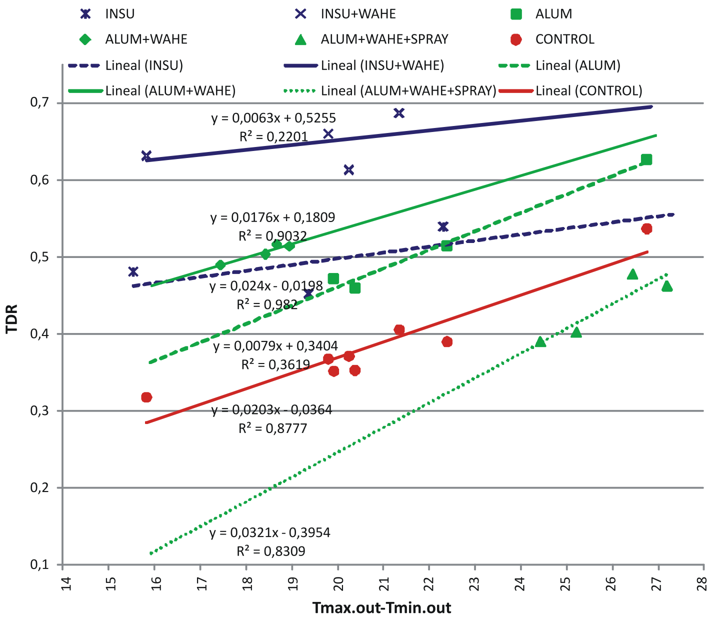

Figure 7: Correlation between the daily outdoor temperature swing and the daily TDR in pond the different pond roof configurations and the control cell

The equations that predict the TDR in each pond roof prototype are listed below:
Insulated pond roof with sprays (INSU):

$$TDR = 0.0024(T_{max\text{-}out}\text{-}T_{min\text{-}out}) – 0.0198 \quad (2)$$

Insulated pond roof with sprays and WAHE (INSU+WAHE):

$$TDR = 0.0063(T_{max\text{-}out}\text{-}T_{min\text{-}out}) – 0.5255 \quad (3)$$

Pond roof covered with aluminum plate (ALUM):

$$TDR = 0.0176(T_{max\text{-}out}\text{-}T_{min\text{-}out}) – 0.1809 \quad (4)$$

Pond roof covered with aluminum plate and WAHE (ALUM+WAHE):

$$TDR = 0.0203(T_{max\text{-}out}\text{-}T_{min\text{-}out}) – 0.0364 \quad (5)$$

After TDR is calculated for a building using Eqs. (2) to (5), it is possible to predict the indoor maximum temperature using equation (1) and solving for $T_{max\text{-}in.}$

$$T_{max\text{-}in} = T_{max\text{-}out} - [TDR * (T_{max\text{-}out}\text{-}T_{min\text{-}out})] \quad (6)$$

Where outdoor maximum and minimum temperatures, or daily temperature swing, must be known. These equations could be used in buildings with lightweight walls, south facing shaded windows and the selected pond roof prototype to predict maximum indoor temperatures.

Conclusion

Previous papers have demonstrated the cooling potential of different pond roofs coupled directly (conductively) with the indoor space for dissipating heat from the building, either by nocturnal long wave radiation to the sky, simple convection to exterior ambient air and evaporative cooling. This paper evaluates two pond roof configurations and demonstrates that their performance is better than a code compliant insulated roof. In addition, their cooling potential could be considerably improved by a WAHE system that re-circulates de indoor air between the cell and the pond roof.

Results show that the better performance is obtained by the insulated roof with sprays at night and WAHE system operating all time. This roof configuration, that is 0.23 better than a code compliant insulated roof (control cell), can keep the indoor temperature under 24 ºC even with outdoor temperature above 35 ºC. Therefore, a difference of more than 10 ºC is recorded. When the WAHE is not operating the system cooling potential decreases an average of 0.12. On the other hand, the efficiency of the pond roof covered with aluminum plate is an average of 0.09 better than the control cell. This percentage is improved to 0.12 when the WAHE system operates.

Future research should include more series to experimentally evaluate other pond roof configurations with a fan sensor that re-circulates the indoor air through the WAHE or provide natural ventilation as required according to seasonal variations.

Acknowledgements

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PLEA 2017 EDINBURGH
Design to Thrive

Rethinking the market-driven urban block in Buenos

Camila Ines Della Bitta[1]

[1] MArch Sustainable Environmental Design 2012-2014, Architectural Association School of Architecture, London, UK, camiladb@gmail.com

Abstract: The paper focuses on the environmental design factors that should be considered in the process of urban densification taking place in Buenos Aires, Argentina's largest city and the second largest in South America after Sao Paulo. It follows from a recent study of a typical Buenos Aires urban block in the area of Palermo, a developing neighbourhood where finding land for the construction of new high-rise residential buildings has led to the demolition of much of the heritage tissue. The parameters affecting the environmental performance of the different building typologies that coexist within the city's urban blocks were studied to identify constraints and opportunities for improving indoor as well as outdoor conditions. The paper will present proposals concerned with improving environmental quality and minimizing energy consumption of the new developments, while being cognizant of the developer's capital cost limits. The proposals encompass improvements to the existing heritage houses to prevent their demolition, thus preserving their interesting spatiality which creates a sense of the house in the middle of a city. Finally, the proposals also encompass improvements to open spaces at the centre of the blocks and use of rooftops for communal activities.

Keywords: density, urban block, housing, open spaces, urban typologies

Introduction

In the last couples of decades cities around the world have been experiencing a significant increase in population, due to not only demographic growth but also migration from rural to urban areas. The city of Buenos Aires has been no exception. Buenos Aires is the main and biggest city in Argentina. The country's total population is approximately 40 million, unevenly distributed along the territory. Almost half of the population is concentrated in the province of Buenos Aires and 70% of these live in the City of Buenos Aires. The city of Buenos Aires is divided into two areas: Capital Federal (The city centre) and "Gran Buenos Aires," (The suburbs). Although the suburbs account for approximately 75% of the city's total population, the city centre has a considerably higher density: 14.000 Hab/Km^2 compared to 2000 Hab/Km^2 (INDEC, 2010).

Over the last decades the urban growth has been characterized by urban sprawl towards the peripheries, while the population in the city centre has remained constant. This type of growth incentives social division and increase carbon emissions and energy demand (Burdett and Rodde, 2011). The densification in Capital Federal should be encouraged as it is proven that dense, compact and mixed use urban tissues is energy and resource efficient (Burdett and Rodde, 2011). It is vital that cities provide diversity in a same area: working, residential, commercial, recreational spaces, public transport and services. The closeness to each other will allow inhabitants to walk from one place to the other without depending on the use of a car.

The paper addresses the issue of densification by focusing on a typical block in Capital Federal. The densification in the city has been done by destroying the existing heritage houses, losing the identity they provide to the city and their interesting indoor spatial qualities. The aim of the paper is to provide ways in which these heritage houses can be integrated into the densification process, and at the same time to address the issue of lack of outdoor public spaces in this area.

Climate analysis

The City of Buenos Aires (34°36'S, 58°26'W), is located in a warm template area (IRAM). Throughout the year, the temperature fluctuates between a maximum mean monthly temperature of 25 °C in December-January to 10 °C in June-July. Three seasons can be recognised: a warm period between November and March, with mean temperatures between 20-25 °C; a mild season in April, September and October, with mean temperatures between 15-20 °C; and a cool period between May and August with mean temperatures below 15 °C (Fig. 1).

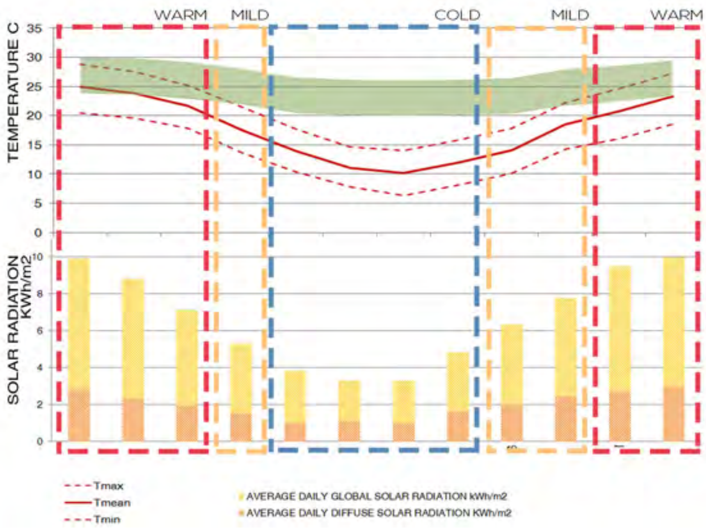

Fig.1: Annual mean temperatures and solar global radiation. Source: After Meteonorm 7.0.

Area of intervention

The paper focuses on Palermo neighbourhood. The main reasons are:

-Palermo registered the highest amount of constructed meter squares of new residential buildings during the last couple of years (Atlas, 2009).

-It is the neighbourhood with the largest and densest population, accounting for 8% of the total population of Capital Federal (INDEC, 2010).

-The distribution of public green outdoor spaces is not convenient in Palermo, as seen by the fact that it is the neighbourhood with the highest amount of population without access to a recreational public space in a 500m radius. The area present big expansions of public parks, but a considerable portion of the population resides far away from these areas (Fig. 2).

There is a need to create an acupuncture design of small and accessible parks for the area, in order to create a more homogeneous distribution of these spaces. These public spaces not only contribute to dissipate negative environmental conditions, but also contribute to social encounter.

Fig. 2: Distances to public green spaces. Source: After Atlas, 2010.

Once the area of intervention was selected, the criterion of selection of a block was based on identifying where it is allowed by the regulation to build the most. Once the block was chosen, the types of building which will be preserved were identified, which turned out to be two: the heritage buildings and the already new builds. It is taken into account that in the developers scenario everything would be demolished and the maximum volume allowed would be constructed in order to maximize the sellable square meters (Fig. 3). This will be following the existing building regulations, one regulate the general urban form (Maximum heights, amount of meter squares, footprint, uses, etc.), and another regulate the habitable conditions inside the dwellings (Minimum size of windows, minimum ventilation required, etc.) (Code, 1977).

Fig. 3: Comparison between the amounts of square meters constructed in each scenario.

The main challenges of the project are:

-How to make the heritage houses more competitive, in order for them not to be demolished?

-How should public space be introduced into the block?

Analytic work

The heritage buildings and new builds are analysed further, in order to determine how these thermally perform in relation to their construction type.

The thermal analysis was performed for the front unit in the heritage houses. A Base case, which assumes how the heritage houses are constructed, was analysed.

During the cool period the highest loses were experienced through the construction: windows, walls and roof. By improving the envelope by adding insulation and applying night shutters during the night, the heat loads were reduced drastically from 31 KWh/m^2 to 6 KWh/m^2. During the warm period (Fig. 4) the highest heat gains are from solar gains. Hence, by improving the envelope and applying shutters to avoid solar penetration inside the room, the cooling loads are reduced significantly. The free-running temperatures in the case of the improved unit stays within the comfort band almost all of the time, reducing peak temperatures from 34 °C to 30 °C.

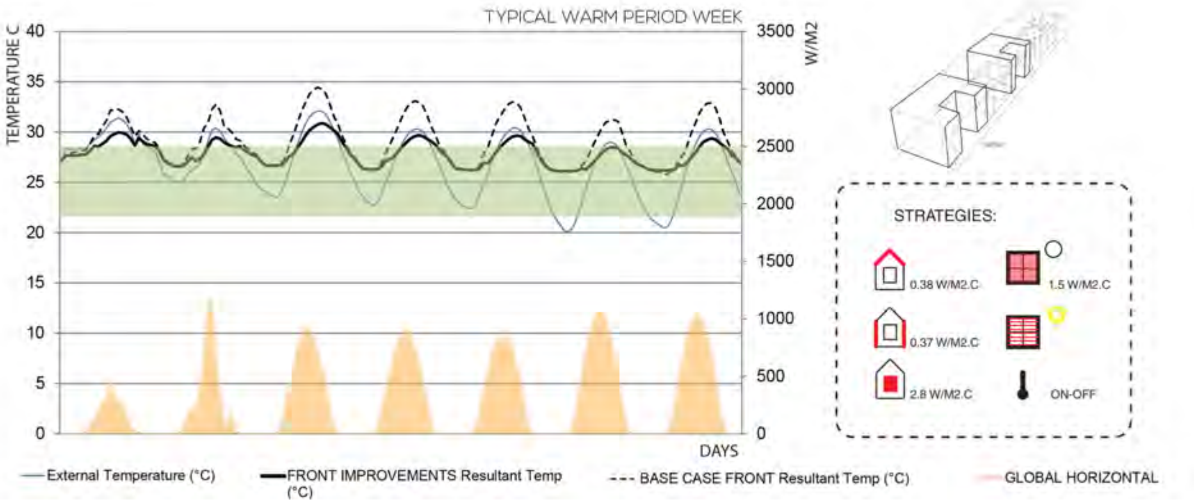

Fig. 4: Free-running temperatures inside the unit in a typical warm period week. Source: After TAS.

The thermal analysis was performed for a unit in the between party wall buildings located at 1st floor. The Base case was analysed, assuming they are constructed in the way currently implemented by developers.

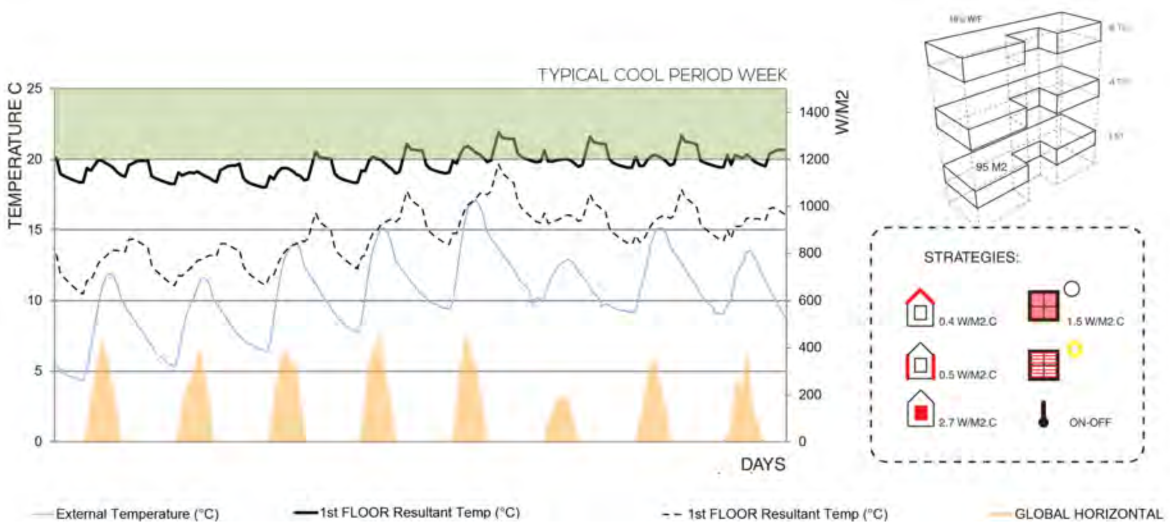

Fig. 5: Free-running temperatures inside the unit in a typical cool period week. Source: After TAS.

During the cool period (Fig.5) the highest loses were experienced through the construction: windows, walls and roof. By improving the envelope by adding insulation and applying night shutters during the night the heat loads were reduced drastically. The free-running temperatures of the improved unit mostly stay within the comfort band, presenting lower temperatures during the night. During the warm period the highest heat gains are from solar gains. Therefore, improving the envelope and applying a blind the cooling loads are reduced significantly. The free-running temperatures of the improved unit remains within the comfort band most of the time, assuming that independence of mechanical means of cooling could be achieved.

Design concept

As mentioned before, the city's growth leads to scarcity of public outdoor space, mainly because most of the investment in the city came from private developers. This project studies the possibility of providing more vitality on the Ground floor to promote social encounter. The block will be “perforated” at ground level in order to allow the people to access and share the central space of the block, allowing a network of public spaces which enhance the connectivity as an urban scale. The environmental conditions are analysed in order to optimize the type of program and activities that will be located there.

Fig. 6: Design brief of the project.

The urban block is currently planned to be constructed by private investors who, following the urban code for construction, destine the outer edge of the ground floor to residential buildings, while the private core is usually destined for private parking. The idea is to “crack” the volume of the block and allow access from the public to the central space. There will be two means of access: two main circulations through the new builds, and four secondary and more local accesses through the five heritage houses (Fig. 6). In this way, 2,400 m^2 of public outdoor space is provided to the neighbourhood. The removed parking area will be replaced by underground parking, providing the same number of parking spaces. Independent designer shops, bars and restaurants, will be located at ground level which will bring life to the ground floor with the added opportunity to enjoy the outdoors.

A mapping of the different microclimates was performed, tracing the percentage of hours of direct solar radiation and the incidence of NE wind speeds. This was done for the warm period and the cool period, in order to recognise the most desirable areas. Two distinct zones in the courtyard can be identified as the result of the mappings: the central area, with wider views to the sky resulting in more solar access, and the corner spaces, with less exposure to the sun. In the central area as the sun patch moves along the courtyard, an open plan was designed in order to allow the free movement along the park. The children’s playground was placed in the sunniest spot, which allows the opportunity to use it, in sunny days, even in the cool season. For the warm period, a line of deciduous trees were placed along the circulations to provide protection from the sun. In the corner spaces which are less exposed to the sun. The expansions of the cafeterias, restaurants, bars and kiosks were placed in this area. When the weather is not warm enough, people will stay indoors.

There are some moments during the cool season that the occupant will not find the environmental conditions on the ground floor adequate. This will be the opportunity to move to the rooftop, which will be unobstructed from the surrounding buildings throughout all the seasons. All the rooftops that are at the same level +26.50m will be connected introducing an additional 3,300 m^2 of communal space (Fig. 6) that could be enjoyed due to the good weather conditions in Buenos Aires.

Special attention is placed on the treatment of shading devices in the rooftop, in order for it to be enjoyed during the warm season. In addition, such as it is unobstructed to the sun, so it is from the wind as well. At this level the wind flows can reach 3-5 m/s. A wind of 5 m/s could represent a reduction of 14 °C in the feeling of the temperature (CIBSE, Guide A, 2006). This could present problems in the outdoor comfort during the cool period. A perimeter rail to be able to control the exposure to the wind in certain areas is studied.

In Fig. 7 the different combinations of pergolas and railing that were used are represented. Through this circulation there are some sitting areas where the user can stop and sit down to enjoy the view. The pergola has mainly two shapes: a “C” shape that allows views to the courtyard and frames a sitting area protected from the sun, or an “O” shape that encourages a simple circulation while still having views. The railing follows this main circulation and, depending on the chosen combination, different levels of protection or exposure to the wind are created.

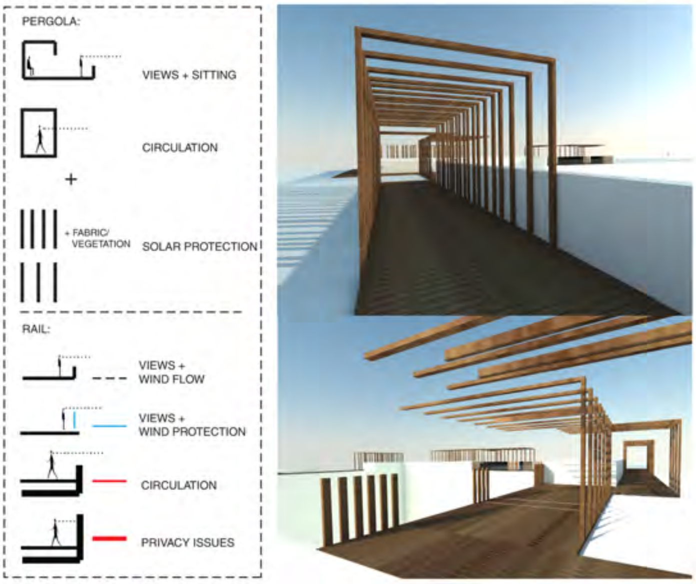

Fig. 7: Pergola and railing combinations.

Avoiding the demolition of the existing heritage tissue is the main challenge. The positive qualities and identity they provide to the urban scene is motivation enough to rethink them and propose a strategy to motivate an interest and investment in them. In a developer’s scenario the heritage houses would be demolished and as much square meters as possible would be built. This would involve 3400 m^2 of demolition works. This shows yet another advantage of preserving the heritage houses: avoiding demolition costs and savings in embodied energy from the materials. Refurbishment of existing buildings is considered one of the most successful sustainable measures: reduction of the use of materials, energy and contamination that a new construction would cause. (Brophy, V and J.O. Lewis, 2011).

In order to create interest in the heritage houses, a densification process is proposed. Due to its construction type (45 cm. brick wall), the existing structure allows the addition of 3 light well type construction levels.

The plots assigned for new developments currently contain buildings without any architectural value: houses constructed in the ‘80s and storage buildings. The proposal is to demolish these, and increase densification following the processes allowed by the code.

Final considerations

The paper studies the possibility of taking advantage of the solar radiation in order to cover some of the block’s electricity demand. In the case of Argentina, an emerging country, the electricity demand is constantly increasing. Electricity production is responsible for carbon emissions to the environment, as approximately 60% is generated from petrol and natural gas (Energy department, 2011). This, together with the electrical crisis that Argentina is experiencing right now (due to the high demand and lack of investment) makes the possibility of developing renewable energies interesting.

The current challenge is that the electricity costs in Argentina are extremely cheap, caused by high levels of state subsidies. This does not motivate neither the user nor the developer to invest in renewables energies. Although there is currently no stimulus from the government, we can assume that there will be. From the total roof surface 1360 m2 are available for placing photovoltaic ("PV") solar panels. The best inclination for these panels, in order to maximize the Global horizontal radiation, is 30° (Della Bitta, C., 2014). With this inclination the incident solar radiation would be 1900 KWh/m2/yr facing N.

Allocating 50% of the available area to Solar panels, 26% of the block's electricity demand (78880 KWh/yr) will be covered by internal generation, reducing the dependence on the national electricity grid. Furthermore, allocating the other 50 % of the available area to solar thermal would reduce the electricity used to heat water by 60% (183600 KWh/yr).

The Proposal's value added exceeds that of the Developers by almost US$ 10 million. This is mainly for two reasons: A 10% price premium on residential units (product of the enhanced design and access to green spaces), and the additional m^2 generated for commercial purposes (which can be sold at US$ 3300/m^2). These two factors increase the block's value by approximately US$ 13.5 million. On the cost side, the Proposal costs exceed that of the Developers by approximately US$ 3.5 million, mainly caused by the deployment of the underground parking lot. The development cost of the residential area is only slightly higher due to the addition of expanded polystyrene as insulation, which is a relatively inexpensive material (US$ 1 per m^2).

The proposal's flats are 30% more energy efficient as they do not rely on the use of the air conditioner and are dependent on heating during fewer hours. As explained if a renewable energy system is installed, this would result in significant reductions of the energy demands. Considering the block as a whole, the proposal would demand 62% less electricity than the block designed by the developers. However, as electricity prices are heavily subsidized in Argentina, the investment in renewable generation units is not economical for individuals, and hence should count with financial aid from the government.

The project proposes 2400 m2 of additional public outdoor space. As discussed earlier, this feature will provide benefits not only to the inhabitants of the block, but to the whole neighbourhood of Palermo.

Conclusion

This paper offers ideas and guidelines on how to enhance the densification process of the existing urban tissue, while preserving the architectural features provided by the heritage houses. Furthermore, the design of a public outdoor space is outlined, in order to address the current lack of public spaces.

The analyses performed related to the new developments lead to a design in accordance to the current urban and construction codes, and in line with the developer's capital cost limits, but with much better energy efficiency and environmental qualities.

The densification of the heritage houses will greatly diminish the incentives to demolish them, which will improve the overall urban quality as they will preserve the city's identity. The promotion of mix-uses in the block will reduce the occupants' dependency on the car, as they will be able to satisfy most of their needs within a walking distance. Buenos Aires' mild weather conditions motivate the idea of exploiting outdoor spaces for social encounter. Projects should be designed for all social backgrounds, in order to provide the possibility of integration and avoid social ghettos. The regulation should be amended in order to support these intentions, since the city's wellbeing cannot be left completely to the market forces.

The main limitation encountered in this dissertation, which limited the exploration of new spatial configurations, are the market forces which encourage developers to build the maximum amount of square meters permitted by the regulation. New combinations of maximum heights and total amount of constructed square meters allowed should be explored in order to achieve high densities in conjunction with interesting indoor spatiality: bigger patios to achieve minimum daylight values, double height roofs and deeper facades for solar control.

In Argentina, as is the case in most developing countries, no strong regulations have been implemented to guide the development of the city. The city's welfare should be analysed and planned by a multi-disciplinary taskforce of architects, economists, sociologists, politicians, and the society as a whole. Only in this way will a balance between social welfare, architectural design and market incentives be found, which will ensure a densification process in an organized and sustainable way.

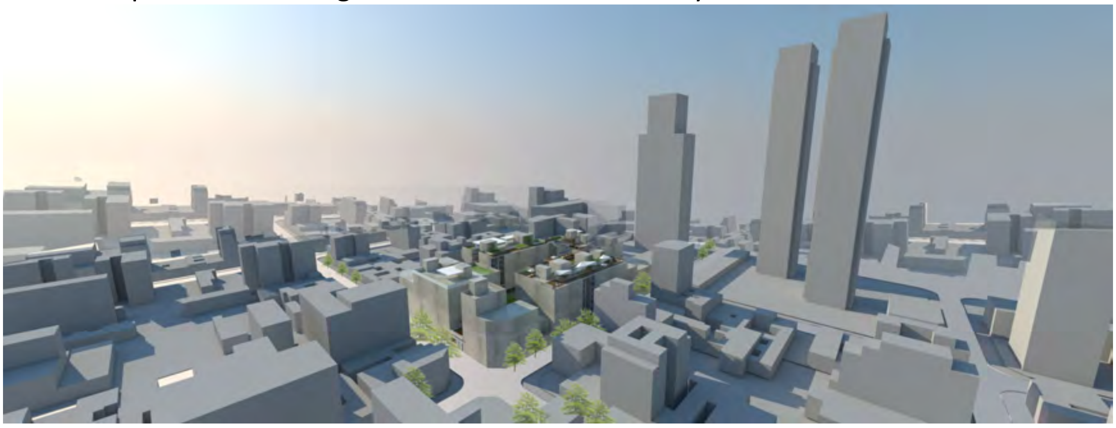

Fig. 8: Aerial view of the project showing the insert of the block in Palermo.

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Design to Thrive

Building-Integrated Carbon Capturing

Harvey Bryan, Ph.D.[1], and Fahad Ben Salamah[2]

[1] Professor, Arizona State University, Tempe, Arizona, USA, harvey.bryan@asu.edu
[2] Ph.D. Student, Arizona State University, Tempe, Arizona, USA, f.bensalamah@gmail.com

Abstract: Building-integrated carbon capturing (BICC) represents a new approach to existing carbon capture technology called Moisture Swing Air Capture Technology, by attempting to integrate this carbon-capturing technology onto building facades. This approach treats building facades as giant artificial leaves that absorb carbon dioxide from the air and convert it into useful carbon-based materials without negatively impacting the environment. In this paper, we will explore how this technology can be modified to be installed on a building's façade in the form of fabric shading devices that absorb carbon dioxide. A cleaning chamber moves along tracks (similar to a window-cleaning system) to moisten the fabric shades and dissolve the bicarbonate on the fibers. This process results in a carbonate and CO_2 liquid that can be compressed and stored for use in a variety of industrial applications. We will use performance data from several non-building devices that have been previously developed and tested to generate the magnitude of the CO_2 that can be captured with this type of technology.

Keywords: Building, Integration, CO_2, Carbon, Capture

Introduction

Achieving stabilization of atmospheric CO_2 concentrations at reasonable levels is looking less and less possible, especially given the present U.S. administration's withdrawal from the Paris Climate Agreement (New York Times, 2017) as well as their termination of the previous administration's Clean Power Plan CO_2 (Davenport et al, 2017). To keep global average warming by century's end to below a 2°C increase (preferable below 1.5°C increase) that is stipulated by the Paris Climate Agreement (FCCC, 2015) will take considerable effort. To reach this global target a host of aggressive and innovative strategies will need to be marshalled to meet this challenge. To date, most strategies have focused on CO_2 mitigation at national levels; while critically important, we also need to engage broader constituencies in combating global warming. Just as distributed renewable strategies have made a significant impact in achieving high levels of renewable penetration in many countries, the authors of this paper believe that a distributed approach can be applied to achieve rapid CO_2 reduction. If this is at all possible, then the question becomes how do we move from a carbon-mitigating approach to one that also includes distributed carbon capturing?

One approach that currently stands out is the process by which nature captures CO_2 from the atmosphere. In essence, we plan to propose a form of biomimicry. Plants have been capturing CO_2 for millennia, turning it into carbohydrates and oxygen in a process known as photosynthesis. What if we treated building façades like giant artificial leaves—that is to say, building facades that could absorb CO_2 from the air and convert it into useful carbon-based materials without negatively impacting the environment? To date, we have reviewed several potential technologies, but the one that looks most promising is called Moisture Swing Air Capture Technology, which has been developed by Dr. Klaus Lackner at Arizona State University's Center for Negative Carbon Emissions (Lackner, 2010). This technology uses filter-like panels made of thin fibers of sorbent material, which is capable of capturing carbon dioxide when in a dry state and then releasing it when moisture is applied. In this paper, we will showcase the Moisture Swing Air Capture Technology and explore in detail how this technology can be modified to be installed on a building façade in the form of fabric shading devices. These devices capture CO_2, which can be compressed and stored for use in a variety of industrial applications.

Capturing carbon dioxide from ambient air

Removing CO_2 from air is not a new thing; it has been around for decades in a process known as CO_2 scrubbing, which is used to generate CO_2-free air (Astarita, 1967). Yet, CO_2 scrubbing is not the same as air capture, because air capture doesn't require removing all the Co_2 from the air. Instead, air capture aims to extract CO_2 from the air efficiently (Lackner et al, 1999). Both technologies use a sorbent material to extract CO_2, with the difference being that air scrubbing requires less sorbent concentration due to the high concentration of CO_2 in the air. Dr. Lackner defines air capture technology in his 2009 article "Capture of Carbon Dioxide from Ambient Air" as follows:

> "A passive, sorbent-based air collector can be viewed as a large filter standing in an airflow with the filter surfaces covered with or made from a CO_2 selective sorbent. Air that comes in contact with sorbent surfaces will relinquish some or all of its CO_2. The larger the surface area and the longer the contact time, the more CO_2 is removed from the air." Pg. 96

In the process of selecting the right sorbent material, Dr. Lackner and his team tried a number of sorbents with the goal being to select a sorbent with lower binding energy (to allow for CO_2 extraction) while maintaining a good CO_2 uptake rate. The evaluation process of different sorbents led to the selection of a strong-base ion-exchange resin that has several appealing properties and suits the air-capture process. One of these properties is the release of CO_2 by exposing it to water. The resin particles are embedded in thin sheets of polypropylene, accounting for almost 60% of the total weight of the material. The sorbent selected was considered a successful choice because they combined two very important properties: low binding energy in the transition from carbonate to bicarbonate, and faster reaction kinetics (Lackner, 2009).

The successful selection of the sorbent leads to the possibility of creating a cycle where CO_2 can be loaded into the resin and then extracted from it through the application of moisture. Once the resin is dry, it will again capture CO_2. To put this cycle into practice, the thin polypropylene sheets with the embodied resin is folded in the planes of the air filter to maximize the amount of sorbent material. They are then exposed to airflow to start the capturing process. Once the sheets are loaded with CO_2, the resin is then exposed to water inside a sealed enclosure, from which the air has been removed. The moisture drives the CO_2 out of the resin, creating a gas that can be compressed and stored. Once the resin is dry, the cycle will continue by absorbing more CO_2 (Lackner, 2009).

The successful selection of sorbent and the laboratory experiments of the CO_2 capturing cycle lead to the design of the carbon carousel machine proposed by Dr. Lackner, which will be described in detail in the following section of the paper.

Carbon carousel: One big filter

The goal of Dr. Lackner's team is to design a device that can be built on the basis of current state-of-the-art technology and packaged in a single cargo shipping container for ease of transportation. The ability to transport such a device will not limit the device for a particular site. As CO_2 is evenly distributed in the atmosphere, the ability to transport such device will allow CO_2 capturing wherever it has been generated around the world. This device would be capable of capturing one ton of CO_2 per day, by collecting one ton per day, the device will provide an excellent scale for its first commercial application (Lackner, 2009).

Figure 1. Carbon Carousel (Source: Kevin Hand, Courtesy of Columbia University, 2010).

The envisioned apparatus will mimic the laboratory experiment of carbon capturing from airflow but on a larger scale. The apparatus will involve a set of air filters that are 1 m wide, 2.5 m tall, from 0.3 m to 0.4 m thick. Each air filter has a total surface area that is equal to 2.5 m^2. The design was intended for an air speed of 1 m/sec across the filter, which is suitable for locations with air speed of several meters per second. A number of various geometries were explored for the design of the air filter to maximize the flow of air and to allow for resin embodiment within the sheets. The selected design was a honeycomb-like structure with narrow but straight passages that function in a way similar to air filters that collect particles from airflow in a duct. Based on the filter design properties and concentration of the resin material, the continuous deployment of thirty air filters would capture one ton per day. However, due to the time required for recovery (the drying of filters takes a noticeably long time), the apparatus was designed to contain 60 filters to ensure a high rate of collection (Lackner, 2009).

Carbon dioxide air filters are placed on an automated conveyor, where the filters will be exposed to natural airflow. It is estimated that it will take one hour for the filter to become loaded with CO_2. Once the filter is saturated with CO_2, an elevator-like moving mechanism removes the air filter and place it in the evacuation chamber where the process of extracting CO_2 takes place.

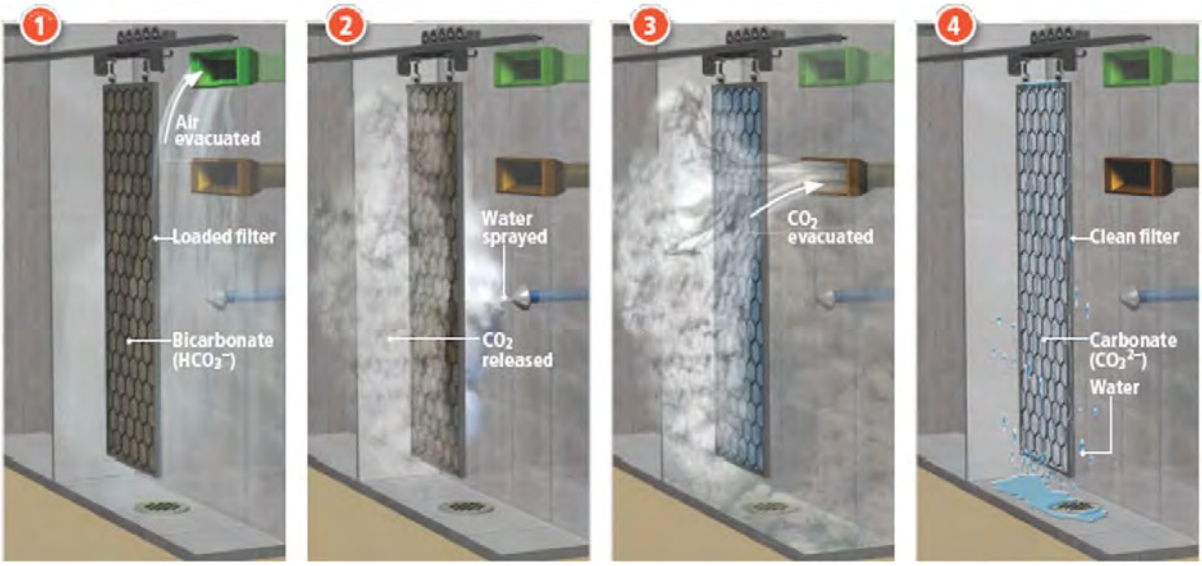

Figure 2. Cleaning Process (Source: Kevin Hand, Courtesy of Columbia University, 2010).

There are six chambers within the shipping container, and each holds 5 filter units. Once the chamber is filled with filter units, the air is evacuated. The filters are exposed to moisture, either by exposing them to briny water or by spraying clean water into the chamber to dissolve the bicarbonate on the fibers, which produces carbonate and CO_2. The CO_2 will be evacuated and compressed into a storage chamber, and the water drained and collected for further CO_2 extraction (Lackner, 2010).

The analysis of the to operate such a device showed that it can be operated using only minimal energy. In the first step, the automated conveyors and elevator mechanism move the air filters into and out of the chambers. In the second step, the air is removed from the air chamber. The third step consumes the largest amount energy in the system, as it involves the compression of CO_2 from 5 kPa to 6.7 MPa in its liquid form. The last energy-consuming step involves the compression and condensation of water vapor (Lackner, 2009).

It is estimated that the total energy required to operate such a system is equivalent to 1.1 Mj/kg of CO_2 (Lackner, 2008). Compared with the amount of CO_2 generated as a result of such an energy requirement, even in a carbon-intensive economy like China, the CO_2 captured using this system is almost 4 times the amount CO_2 released as a result of the process of energy generated for its use (Lackner, 2009).

Building-Integrated carbon capturing

The potential carbon-capturing technology described earlier in this paper will be modified to be installed on building surfaces in the form of shading devices. This method will allow buildings to lower solar heat gain through shading while simultaneously capturing CO_2 through the air filters attached to the building facade. Unlike the carbon carousel machine, *building-integrated carbon capturing* (BICC) will allow for carbon capturing in cities and urban settlements where the collected CO_2 can be stored for local use or shipped elsewhere for other applications.

BICC will mimic the properties of the air filters used in the carbon carousel machine. Thin fibers of sorbent material are arranged in a honeycomb-like arrangement that is similar to air duct filters. The alterations to the filter height, depth, and thickness are necessary to adapt the filter size to be implemented on building façades. The air filters in this system are 0.6 m in depth, 1.6 m in height, and 0.1 m in thickness and it is similar to the air filters in the carbon carousel machine with respect to the sorbent material used. The filter devices will be attached to building façades vertically, forming a column of air filters that runs from the top of the building to the bottom, arranged in a way that fits between the window bays.

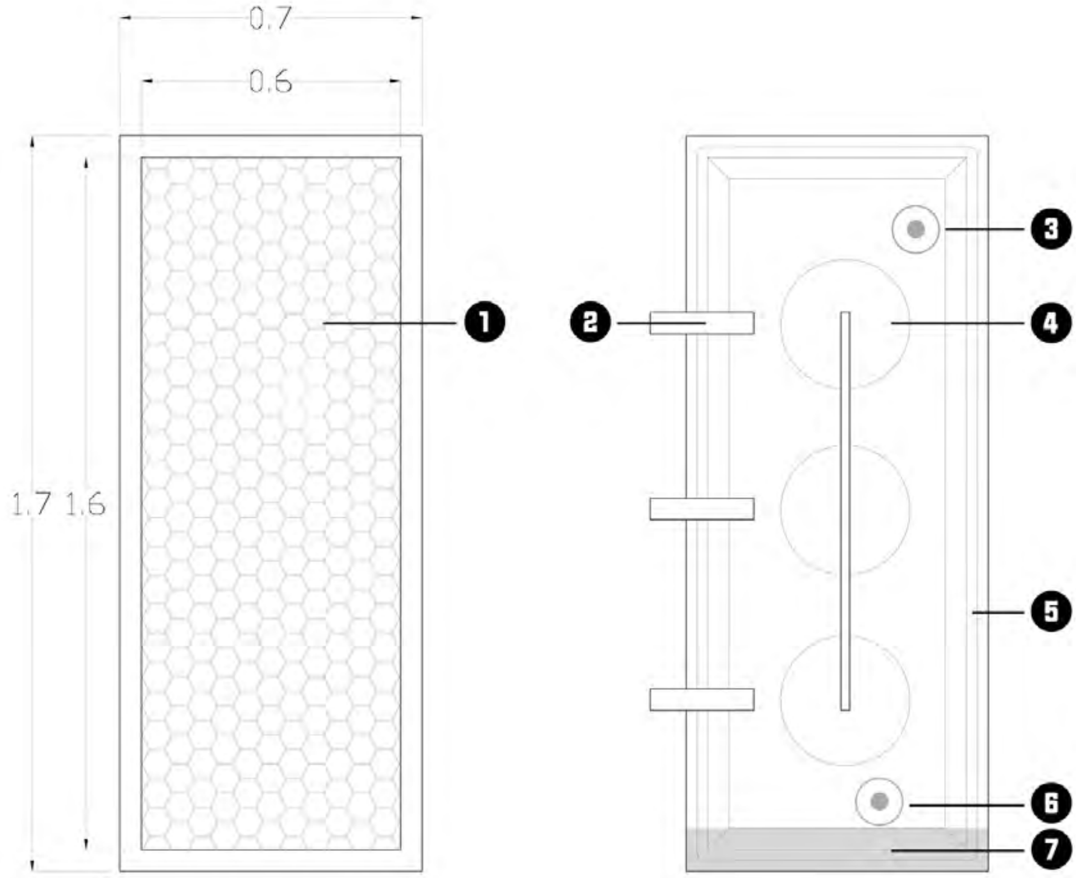

Figure 3. Front elevations of air filter (left) and cleaning chamber (right). 1) Polypropylene sheets. 2) Connection to tracks. 3) Hose to CO_2 tank. 4) Water Sprayers. 5) Sealant. 6) Hose to water tank. 7) Drain

The panels will be exposed to the air in a fixed and static condition. Unlike in the carbon carousel, the BICC panels will not move through a moving conveyor into the cleaning chamber. Once the air filters are loaded with CO_2, a moveable cleaning chamber has been designed as a replacement for the large stationary cleaning chamber in the carbon carousel machine. The moveable chamber moves along tracks (similar to a window-cleaning system) to moisten the fabric shades and dissolve the bicarbonate on the fibers. This produces carbonate and CO_2 liquid. This liquid undergoes processing to separate the water from the CO_2, with the water being recycled back into the cleaning apparatus and the CO_2 being compressed and stored for use in a variety of industrial applications. The cleaning chamber moves to the next panel while solar radiation dries the fabric shade panels, making them ready for the next cycle.

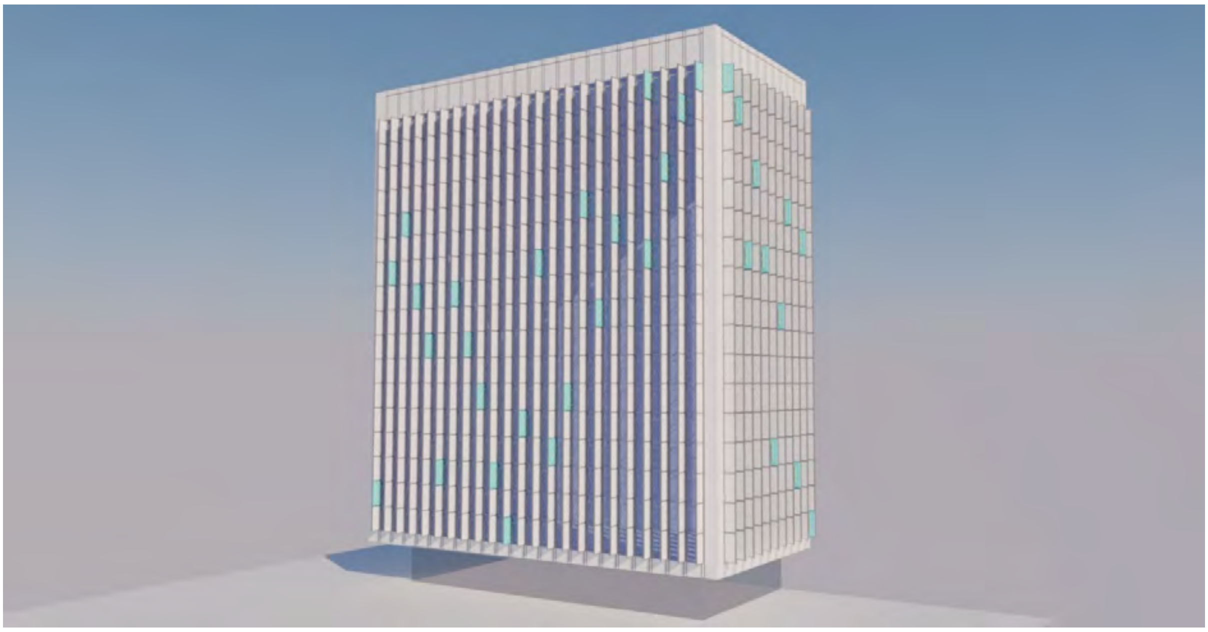

Figure 4. Representation of cleaning chambers during operation

Unlike the stationary cleaning chambers on the carbon carousel machine, the cleaning chambers for this system will move on tracks along the building's façade, similar to a window-cleaning system. The automated cleaning chamber will be connected through sealed hoses to two storage tanks—one for water used to extract the CO_2, and the other for storing the collected CO_2.

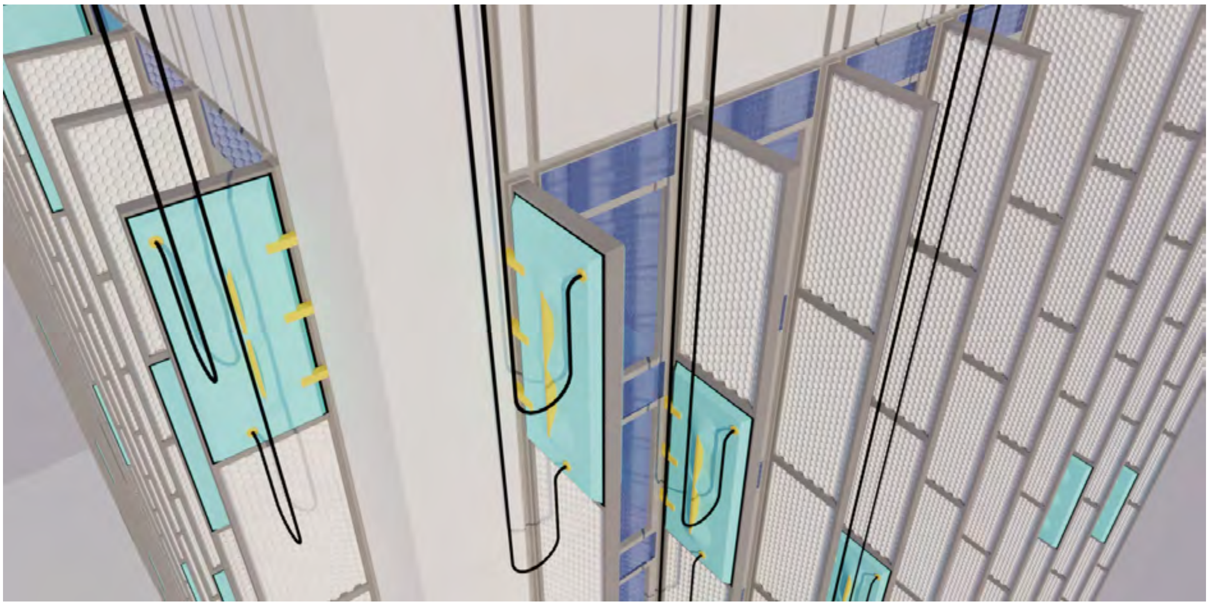

Figure 5. Representation of cleaning chambers with hoses connected to roof tanks

To determine the number of moveable automated cleaning chambers a building requires, the design team must first calculate the number of air filters that will be integrated with the façades. The team must also take into consideration that the carbon-washing process takes almost one hour for an air filter with that type to be loaded with CO_2 in addition to an equal amount of time for recovery and drying of the resin.

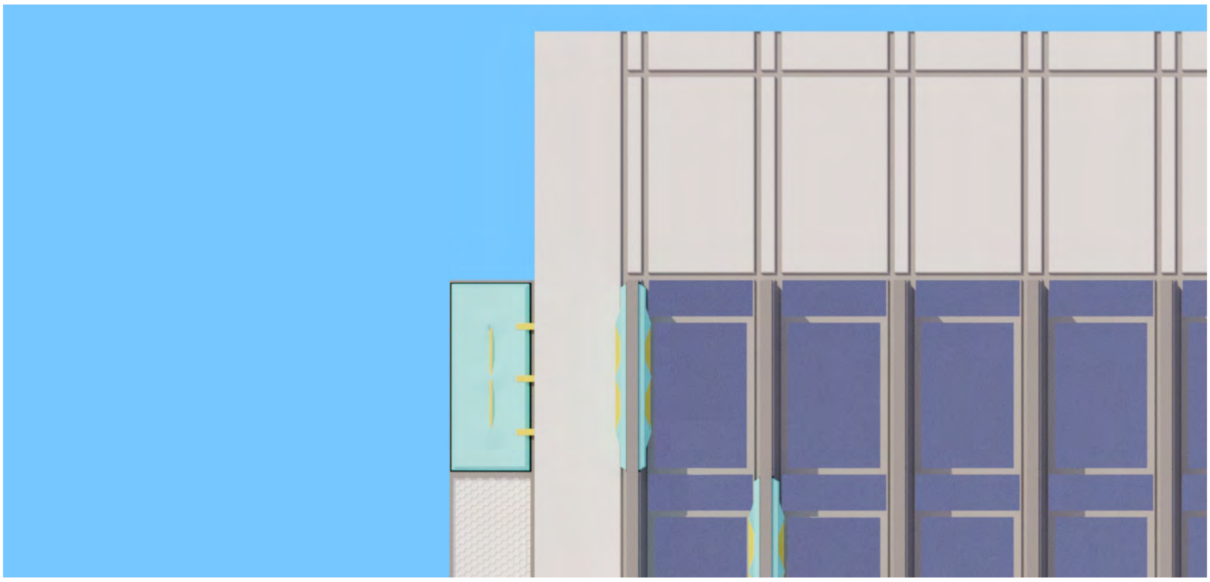

Figure 6. Cleaning chambers and tracks along building façade

The amount of CO_2 collected by such system will depend on the design, the available façade area, the height of the building, and the climate conditions at that particular site. To get a rough estimate of what one floor of a building could collect, we must set certain design parameters that could control the integration of the system on buildings. The thin side (0.1 m) of air filters must be placed perpendicular to the façade. The filters need to be spaced at least one meter away from one another to allow for at least two automated cleaning chambers to move along.

To calculate roughly how much CO_2 a building fitted with BICC would collect, one must know the design properties for the particular building. For example, a building that is 25 m in width and 36 m in depth will allow for 22 rows of air filters per floor on the smaller sides of the building and 33 rows per floor on the larger sides of the building. Since the building has 4 surfaces, and the height of the air filter is 1.6 m, the total amount of air filters per floor for this building is 136. Following the data provided by Dr. Lackner regarding how much CO_2 each filter will collect, and taking into consideration the time required for recovery and partial drying, each floor will collect roughly one ton of CO_2 per day.

Discussion and conclusion

We conclude that BICC is physically possible, and it will add a collection system within cities that surpasses the uptake rate of natural CO_2 sinks such as trees by several orders of magnitude. To have a significant impact on carbon emissions in the atmosphere, the uptake rate of a single building must be evaluated by orders of magnitude. A 20-story building similar to the example mentioned earlier would collect almost 20 tons of CO_2 per day. Ten buildings of that size within a city could collect 200 tons of CO_2 per day. That may sound like a very small number in comparison with global CO_2 emissions. The world emits nearly 29 Gt of CO_2 yearly (Lackner, 2009). Almost 750,000 commercial buildings were constructed in the United States between the years 2003 and 2012 (EIA, 2012). If 50% of these buildings implemented the BICC strategy, this would lead to a collection rate of 2.73 Gt/yr, which could have a significant impact on the world's CO_2 emissions.

The system properties and the amount of CO_2 collected by this system can be affected by the air speed in a certain location. If a building has 4 sides, the wind speed along the windward side differs from the wind speed on the leeward side. The difference in airflow may lead to changes in air filter thickness and the amount of sorbent required for collection. A location with fast-blowing air would require a collector with a small frontal area and greater filter depth, whereas another location with slow-blowing air would require a larger frontal area and a thinner filter (Lackner, 2009). This problem can be solved by designing two separate air filter units—one tailored for windward surfaces, and one tailored for leeward surfaces.

The present air-capture device is climate sensitive, meaning that tropical climates with high humidity as well as extremely cold climates may limit the operation of the device. In hot and humid climates, the humidity limits the absorption rate and load capacity of the resin, whereas in cold climates, the collection of CO_2 works, but the drying rate of the filters is much slower than in warmer climates (Lackner, 2009). The sorbent material used for the air filters was designed specifically to work for desert climates where the absorption rate of the resin and the drying time of the filters gives the devices a high collection rate. For such a system to operate successfully in other climates, the air filters must be altered accordingly.

The collected CO_2 has a variety of local uses in local markets, including food production, the carbonation of beverages, refrigeration, or as dry ice (Lackner, 2010). CO_2 can also be used as a cleaning product for dry cleaners, where it can be used as a liquid solvent for cleaning clothes. Another local use would be as a growth stimulator for indoor crops in its gas form. Collected CO_2 can be stored and shipped to remote sites and used in enhanced oil recovery, where the injected CO_2 facilitates the production of oil. Some scientists consider this method to be one of the most successful strategies for storing and disposing of carbon. Another benefit of BICC would be that it could offset past emissions and offers a great solution for offsetting emissions that are hard to avoid, such as emissions from airplanes and automobiles (Lackner, 2009). Once successfully developed and implemented, and in collaboration with other existing technologies such as the carbon carousel, BICC will provide a valuable option, whether through keeping up with the world's emissions or through reducing the CO_2 content in the atmosphere.

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Considerations for extending benefits of energy retrofits at the building level to the building stock

Isaac Guedi Capeluto[1] and Carlos Ernesto Ochoa[2]

[1] Climate and Energy Laboratory in Architecture, Faculty of Architecture and Town Planning, Technion – Israel Institute of Technology, Technion City, Haifa 32000, Israel.
Correspondence email: arrguedi@technion.ac.il;
[2] Climate and Energy Laboratory in Architecture, Faculty of Architecture and Town Planning, Technion – Israel Institute of Technology, Technion City, Haifa 32000, Israel.

Abstract: Enhanced energy performance at the building level is mandated through regulations and certifications such as LEED, BREEAM, EPBD, Passivehaus, etc. Their impact is limited due to the large amount of existing buildings where they are not applied. Prefabricated building envelope energy retrofit systems offer viable alternatives for large-scale implementation, reducing costs and installation times while upgrading comfort levels. The number of buildings requiring refurbishment obliges using non-conventional methods responding to a variety of climates. This paper analyses, through computer modelling, two prefabricated retrofit systems placed on the external side of the existing building envelope. The first one includes mainly passive façade technologies with some user intervention, representing a conventional approach to renovation. The second system features mainly active technologies for application on roof and façades. It represents a more ambitious method to upgrade buildings with the latest technologies, where higher energy savings are the main objective. Both systems feature options for use in different climates. Results show the passive system accounted for 50% of energy savings, but the mainly active system reached 65% using finer control responses and a variety of combinations. Choosing adequate design directions from early design stages will affect effectiveness of retrofit policies.

Keywords: Energy Retrofit, Prefabricated Systems, Design Decisions, Facade, Urban Climate

Introduction

Design consciousness towards enhanced energy performance at the building level has been expressed in different regulations and certifications such as LEED, BREEAM, EPBD, Passivehaus, Minergie, etc (Chandratilake et al, 2013). However, **the global impact of new guidelines on national energy savings is limited due to the large amount of existing buildings constructed before their implementation**. In the United States, around 72% of built space is over 25 years old, previous to the introduction of energy certifications (EIA, 2006); while in the European Union over 50% of residential buildings were made prior to the introduction of the first energy regulations (EBSO, 2017). This makes energy retrofit of buildings a suitable option to minimize energy consumption of the entire building stock in a country and reduce emissions. Additionally, energy retrofit can be a cost-effective solution that also upgrades aesthetics and enhances comfort levels for occupants of structures that do not comply with current standards and expectations.

Nevertheless, as seen from the brief statistics that have been mentioned, the sheer amount of buildings requiring intervention obliges to think of non-conventional methods to implement energy retrofits while producing the least disruption to occupants. Prefabricated façade and roof systems become a suitable option in order to reduce costs and installation times. The idea has even been considered as an energy policy by international bodies (Atanasiu et al, 2011).

Diverse options for integrated prefabricated façade and roof energy retrofit systems have been proposed as research outputs, while others are available on the market as separate components. Although it is out of the scope of this paper to provide a review of each retrofit system, they can be divided into passive and active ones, which satisfy building energy demand or supply (Ma et al, 2012). Combined systems can also be found (Passer et al, 2016).

Each building retrofit system has different characteristics that make them suitable for a variety of cases. Nevertheless, it is usual that early during the retrofit process a decision will be made on applying a particular one. Such decision will affect final retrofit performance. Although ideally the "best" system should be chosen, different criteria and constraints unrelated to energy performance affect selecting one system over the other. Examples include installation costs and local regulations. Choosing a given system option is a not trivial task in building retrofits, which require feasibility studies for different scenarios. To this end, computer simulation is a valuable tool that has helped take decisions in projects of different sizes, including large scale envelope retrofits in healthcare (Staljanssens et al, 2015) and residential buildings (Salvalai et al, 2017).

This paper analyses, through computer modelling, the performance of two prefabricated retrofit systems placed on the external side of the building envelope. It will also serve to explore how early stage retrofit design decisions affect final energy performance, by contrasting a conservative design approach with a performance-driven one. It will also indicate how energy retrofit policies can be affected from application of a given direction.

Description of the retrofit systems under study

Two modular building envelope energy retrofit systems still under development will be explored. The first system features mostly passive façade technologies, with some limited user intervention (Paiho et al, 2015). The second system features a higher degree of automation, using recent technologies that can be applied on the roof and façade (Bresaer, 2017). The former system represents a conventional approach to renovation, which can satisfy factors such as reduced cost and less maintenance. The latter system represents a more ambitious method to upgrade buildings with the latest technologies and where obtaining high energy savings is the main objective. Both systems are purposed for large-scale prefabrication. They are placed on the external side of the existing building envelope without need to demolish existing elements, accommodating a series of different technologies at once. The two systems allow flexible combinations according to each climate case. Their main characteristics are described as follows:

Mostly passive retrofit system

The main climatic strategies implemented by this system are well-known, requiring minimal or no mechanical parts, despite some user intervention needed such as opening and closing shades or regulating air intake. The system is modular, and each module in this system can offer one of the following façade strategies: improvement of insulation levels, improvement of outer surface reflectivity (albedo), glazing upgrading, a manual shading system applied according to season, and a module that regulates passive ventilation during summer. These modules can be used separately and in combination, with each alternative providing different levels of energy savings. Finding which arrangement is best for a given situation depends on studying weather characteristics in order to apply a set of pre-defined strategy choices (Capeluto et al, 2014).

Mostly active retrofit system

This system is characterized by the combination of passive and active strategies, and has more constructive flexibility in terms of modularity. It can be placed on both roof and façade. Passive strategies include improvement of insulation levels to minimum contemporary requirements, improvements in outer reflectivity, and infiltration reduction.

Options that can be chosen according to each particular case include: adding a lightweight super insulating panel, two types of solar collector cavities for air preheating, one with forced ventilation while the other with buoyant flow. There is also glazing improvement with automated solar-tracking external blinds that provide night insulation. Active ventilation is provided through an electric fan. These strategies are regulated by a building management system (BMS), which coordinates them to achieve comfort levels. Figure 1 gives a scheme that represents how the components are placed.

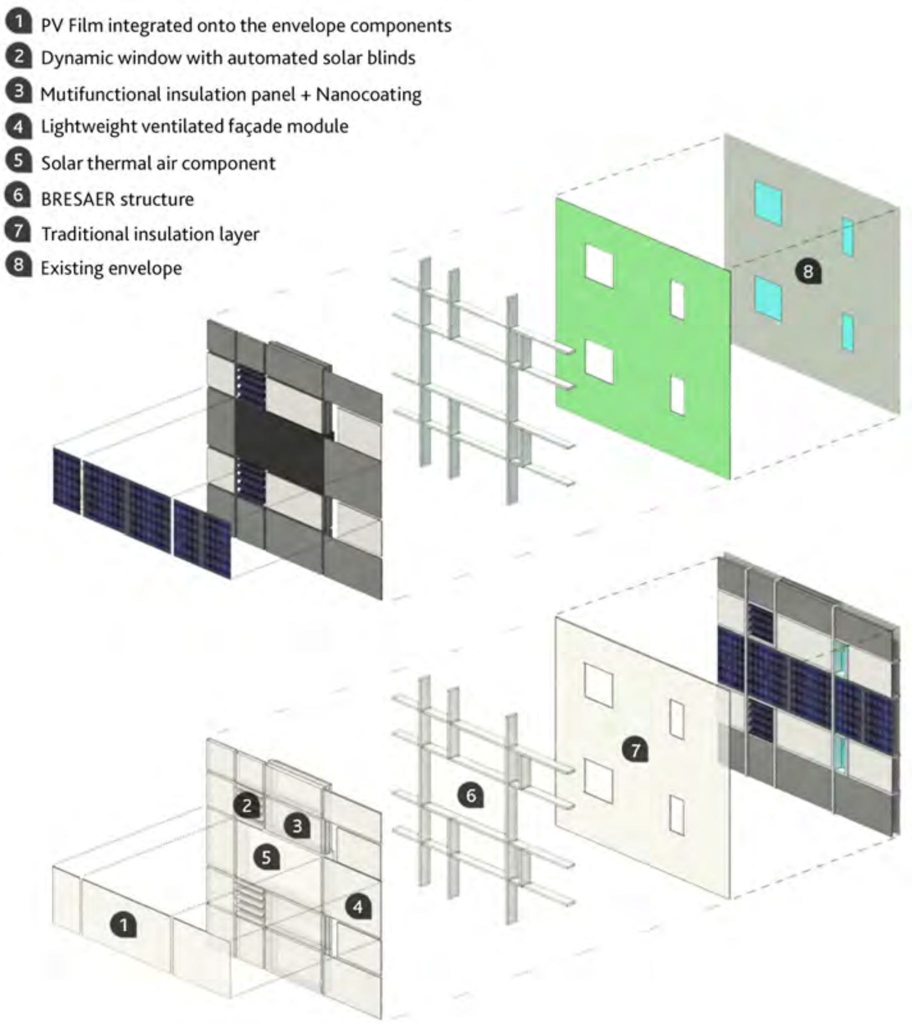

Figure 1. Schematic representation of the mostly active system. Image source: http://www.bresaer.eu

Passive strategies in this system (basic improvements in insulation, infiltration and reflectivity) must be applied together, being a pre-requisite for intervention in any retrofit project. Choices for active strategies are then applied separately or in conjunction, according to the requirements of each location under study. Optionally, a thin-layer photovoltaic panel can also be placed for energy self-generation, but it was not taken into account for this paper. Table 1 shows the strategies used by both systems.

Table 1. Climate strategies followed by each system. X* = applied as prerequisite to the system.

Strategy	Mostly passive system	Mostly active system
Insulation improvement	X	X*
Infiltration reduction	-	X*
Improvement outer reflectivity	X	X*
Glazing improvement only	X	-
Controlled summer time ventilation	X	-
Manual seasonal shading	X	-
Active cavity ventilation and air pre-heating	-	X
Insulating automated outer blinds and glazing improvement	-	X
Highly insulating panel	-	X

Conditions for comparison of the design approaches

A hypothetical case study was made to evaluate both systems focusing on their energy performance. They were modelled using the software EnergyPlus (USDOE, 2017) on a middle-floor apartment located in the urban area of Athens, Greece.

Some of the key parameters that were used for the study are based on examination of building stock databases for that area (Episcope, 2017). The example corresponds to a residential building made before the introduction of the first energy regulations, as a typical situation that would qualify for renovation. Improvement values are based on the Energy Performance for Buildings Directive (EPBD) 2010. The apartment has a floor area of 94.5 m2, with a 1:1 proportion. Window area is 25% of the total floor area, and it is assumed there are no restrictions for conservation or technology selection.

For simplicity, the apartment is assumed to have only one external wall, oriented to the South to represent a favourable location for management of solar radiation, and to test technologies designed to handle natural light penetration.

In the comparison, the external facade was retrofitted with either the active or passive system. Both systems allow a large number of combinations. All possible options were tested in the mostly passive system, but in the case of the mostly active system (which allows for many more options), verification was made on two technology combinations in the façade that could be compared with the passive system, and all strategies together. Yearly energy consumption was calculated for the two systems and detailed for heating, cooling, and where relevant, fan consumption. A summary of the main parameters used for modelling is shown in Table 2.

Table 2. Main characteristics for the residential building under study. Improvement values: EPBD 2010

Feature	Initial	Improvement
Location	Athens, Greece	-
Façade orientation	South	-
Typical apartment floor area (m2)	94.5	-
Typical apartment façade area (m2)	36.5	-
Window area as percentage floor area (%)	25.0	-
Typical existing total load consumption (W/m^2) max.	8.8	-
U-value external wall (W/m^2-K)	2.2	0.42
U-value window (W/m2-K)	6.0	2.0
Visible absorptance	0.7	0.94*
Ventilation, natural (air changes-hour)	4	4*
Recovery rate HVAC (%)	0	50%
Infiltration (air changes-hour)	1.0	0.15*
*not in EPBD		

Results

Energy consumption mostly passive system

Simulation results for this system are shown in Figure 2. Maximum energy savings of about 40-50% are achieved under the described conditions. A total of 11 combinations were checked. As anticipated in a cooling-dominated climate, strategies addressing direct solar penetration such as shading and glazing improvement helped achieve highest energy savings.

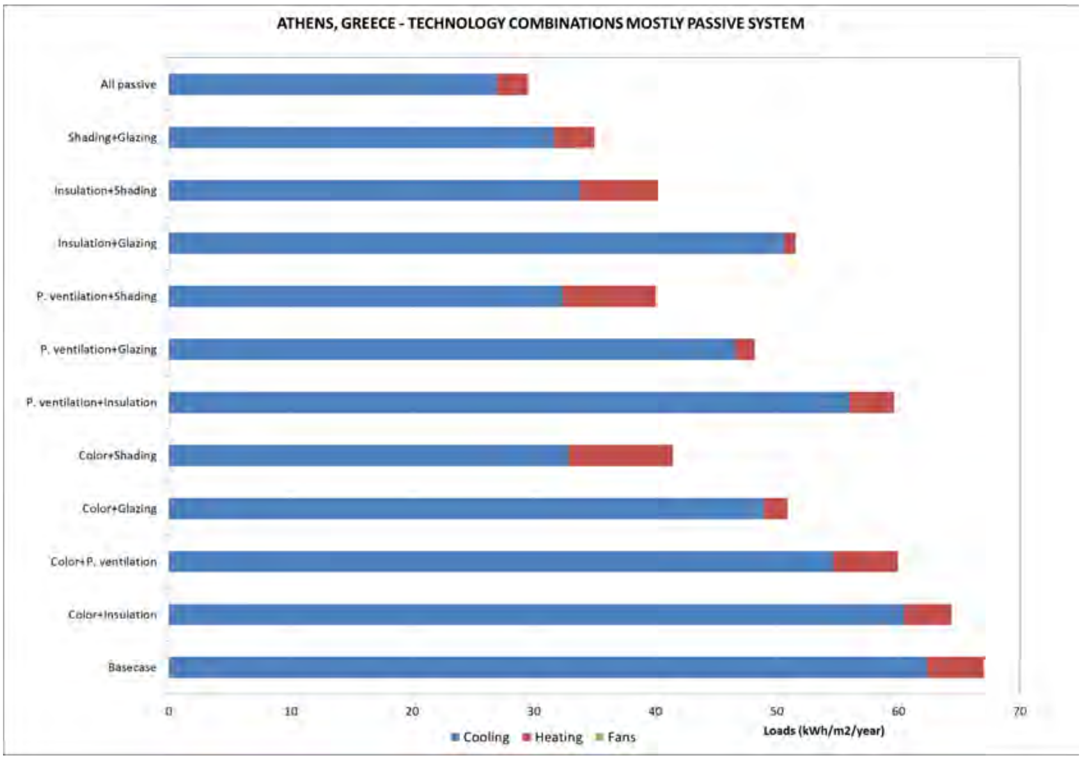

Figure 2. Energy consumption results for a mostly passive system on a residential building facade. Athens, Greece, South orientation

Energy consumption mostly active system

Cooling, heating and ventilation results for simulations using this system can be seen in Figure 3. In total, 6 combinations were studied as well as the influence of system pre-requisites (improvements in basic insulation infiltration and reflectivity). Due to mechanical requirements and resulting low infiltration, electric fan ventilation loads became more noticeable than in the passive system. Heating from external sources was practically not needed when using these active technologies and the pre-requisites.

As expected, active elements brought the highest total energy savings, around 65% when compared to the initial basecase. Heating needs were practically covered by the system. For cooling, which is important for this type of climate, using improved glazing and automated blinds helped reduce cooling consumption around 60% compared to the initial basecase. However, it was observed that despite the addition of all active elements, consumption could not be reduced further in the existing building.

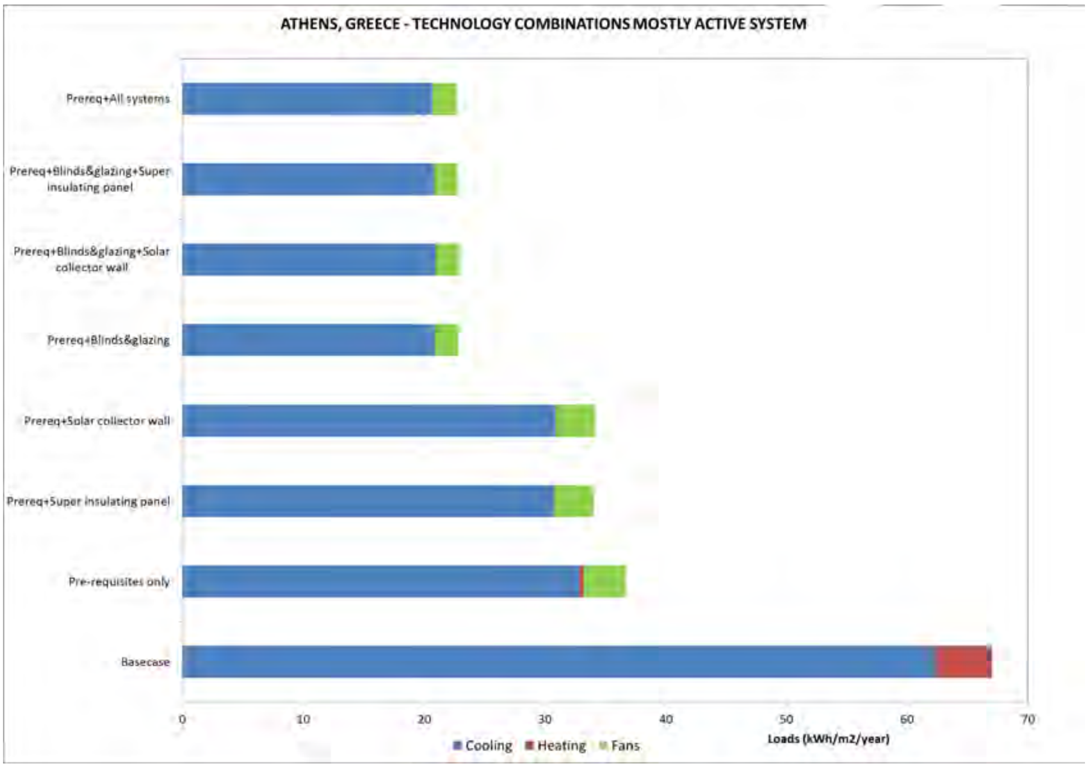

Figure 3. Energy consumption results for a mostly active system on a residential building facade. Athens, Greece, South orientation

Discussion

The mainly active system achieved the highest energy savings due to its adaptability and control systems, while these savings can be achieved using various combinations. This provides an advantage to planners and designers, who can choose a given combination according to the particular needs of their project. The active system, in order to work correctly, had as previous requirements a series of important intervention measures that help reduce energy losses. This enables the active systems to perform correctly and achieve high overall energy savings.

Energy savings achieved after adding the active systems were 40% compared to the basecase. Savings could not be reduced further despite adding all the available options. This suggests that the starting point before retrofit is important, where a “very bad” building in terms of energy consumption will benefit more from upgrading than a more recent, “better” energy-performing one using the same retrofit system.

When extended to the urban level, it can be said that energy saving estimates from renovation are not lineal or cumulative, due to dissimilar energy performances found in diverse sections of the building stock. Although it can be safely assumed that pursuing a high-performance retrofit policy path will bring the highest energy savings, not all buildings will benefit on the same percentage level, with the most recent ones not seeing significant improvements. Therefore, feasibility studies and retrofit regulations must consider differentiated time frames and specific actions for the main historic characteristics in the region’s buildings and focus first on the worst performing buildings first for significant and worthwhile effects.

The two design paths also represent the materialization of different criteria influencing design decisions. Examples include preference of policy makers towards promoting local industry, funding tax incentives for building renovation, influence of payback periods, etc.

Considering the design paths in the retrofit process, planners are faced with deciding on the best elements for obtaining suitable results in the retrofit. Choosing on one path or the other (mostly active or mostly passive) is taken early during the design process and will influence the outcome. Flexibility in taking decisions is also a desirable factor for stakeholders, and the mostly active system presented here has that feature. Such characteristic is convenient when other considerations come into play such as ease of maintenance or initial installation cost. Having different options within the same system will also help adequate and methodological assessments on performance, which need to include relevant criteria that affects the decision outcome (Ochoa et al, 2015).

Conclusions

Energy retrofits are required in the existing building stock to extend the benefit of recent energy certifications and standards. Prefabrication is a suitable alternative for large-scale implementation, but deciding on the most suitable path is an early design stage decision, which will influence final performance, therefore needing careful consideration. Paths need to be chosen according to the starting condition of the building in order to obtain maximum performance, although other factors will influence the final choice, such as cost or local regulations.

The expected impact from energy retrofit interventions has to consider performance of existing buildings according to their main historic constructive characteristics. The mostly passive system provided up to 50% savings while the active system provided higher performance (65% energy savings when compared to the basecase). Additionally, the mostly active system provides high performance through a variety of options that adapt to different project conditions.

Acknowledgments

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The Carbon Balance Index: a simple metric for progress toward zero-net carbon

Mark DeKay[1]

[1] Professor, University of Tennessee, Knoxville, USA, mdekay@utk.edu

Abstract: In North America, “Architecture 2030” has established targets for reducing building fossil fuel use to zero by 2030, now called “zero net carbon” (ZNC). This paper introduces the Carbon Balance Index (CBI) as a simple metric that allows performance comparison along a spectrum from typical buildings that depend entirely on fossil fuels to those that export energy, comparing a range of carbon performance. CBI assesses greenhouse gas production (as CO_2 equivalent) relative to a typical building’s carbon use intensity (CUI), using EUI data categorized by climate and building type. CUI is equal to the building’s EUI times a CO_2e conversion factor/s based on fuel type/s used. CBI is defined as the designed building’s net CUI divided by the CUI of a typical building, expressed as a percentage. The methods for calculating CUI benchmarks, the designed building’s CUI and CBI are explained in simple terms. Building on earlier work on the Energy Balance Index (EBI), the CBI and EBI targets, curves and zero points are compared. Carbon-neutral buildings have CBI = 0. Positive CBI means some fossil fuels are used and carbon is produced, while negative CBI projects “consume” carbon by exporting excess energy and offsetting fossil grid energy.

Keywords: zero net carbon, carbon-neutral, carbon use intensity, energy balance index, carbon metric

Introduction

There are many definitions for net-zero carbon buildings (Riedy, et al, 2011), zero emissions buildings (RCOZEB, 2017), net-zero energy (Sartori, et al, 2012), among many others. What seems like a simple concept, “zero carbon,” can get complicated with issues of lifecycle boundary, operation and construction carbon, building type, climate, grid source energy types and interconnections, spatial boundaries, etc. The question might then be, “Why do we need the subject of this paper, a new carbon metric for buildings?” The reason is not so much about building science precision as it is about the urgency of climate change and expediency of simplicity. As Simon Sinek (2015) puts it, “Simple ideas are easier to understand. Ideas that are easier to understand are repeated. Ideas that are repeated change the world.” In this realm, we need simple.

In the North America, the Architecture 2030 organization has done a good job at making the challenge for the building community clear and simple with their 2030 Targets. The “2030 Challenge” sets targets, shown in Fig. 1, for designers to reduce fossil fuel use incrementally, culminating in *carbon-neutral* building performance by the year 2030 for all new construction and major renovations (Arch 2030, 2011).

At PLEA 2016, DeKay and Giddings (2016) presented the *Energy Balance Index* (EBI) to assesses energy performance relative to a typical building’s *Energy Use Intensity* (EUI) based on climate and building type. The EBI shows that, depending on the level of imported renewables, the 2030 target of “carbon-neutral” can achieve a performance level of *site net-zero energy*, or in some cases something 20% short of that target. The paper finished with outlining the need for and giving a preliminary definition of the *Carbon Balance Index* (CBI), now developed further in this paper.

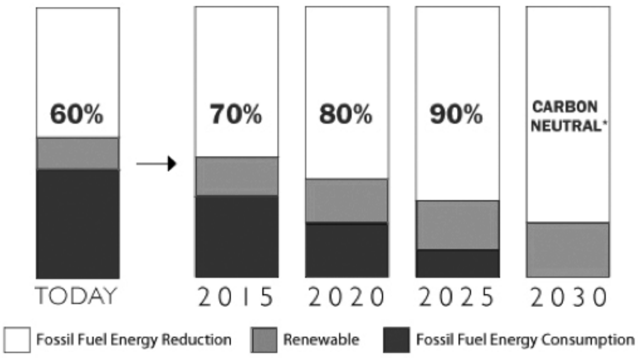

Figure 1: Targets for fossil fuel reduction

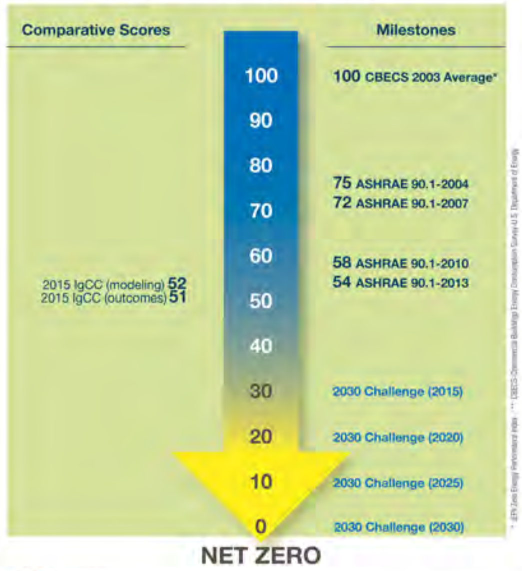

Figure 2. zEPI Scale from NBI

The Issues and Need for a Carbon Index

The need to define an index for carbon performance in buildings came about in part because of numerous related definitions, and the desirability of understanding the relative carbon performance or one building to another, rather than simply the absolute production or consumption value of greenhouse gases. For example, the US EPA's Target Finder allows a relative score for energy, but reports carbon use in "total GHG Emissions," (metric tons CO_2e). This is in contrast to Energy Use Intensity (EUI), which is expressed in energy per unit of floor area per year, and can thus be compared with benchmarks and with other buildings similar in case. Like for energy use, there is a need for measuring carbon on a "more stable, absolute scale that would be used to benchmark buildings, as opposed to the typical percent-better-than-code metric" (NBI, 2017).

Recently, Architecture 2030, along with the New Buildings Institute (NBI, et al, 2016) defined *Zero Net Carbon* (ZNC) as "a highly energy efficient building that produces on-site, or procures, enough carbon-free renewable energy to meet building operations energy consumption annually." In defining "net zero" as linked to carbon and delinked from the building's site boundary, the NBI's coalition has 1) Put the focus on operational energy and carbon, 2) Established a simple legible approach for the complex issues of energy and carbon balance, and 3) Focused the building community on making progress toward solving climate change that is widely inclusive of many building types and site contexts. It aligns with Architecture 2030's emphasis on cities and urban buildings, which in many cases lack good access to solar energy. This is all good, *and* there are problems, the main one being that there is no way to align carbon and energy at any other place on the implied ZNC scale.

Figure 2 shows the *Zero Energy Performance Index* (zEPI) scale as promoted by the New Buildings Institute (2016). Note that this is an *energy* scale with 100 set at the EUI of a benchmark building and zero for "net-zero" energy, with the year 2030 target, which is "carbon-neutral," meaning no fossil fuels used in building operation, aligned to zero. This "net-zero" definition allows imported renewables and so is *not* "site" net-zero energy or carbon. The new Architecture 2030/NBI definition of ZNC also aligns with zero on the zEPI scale, essentially conflating energy and carbon—simple, but rather, too simple.

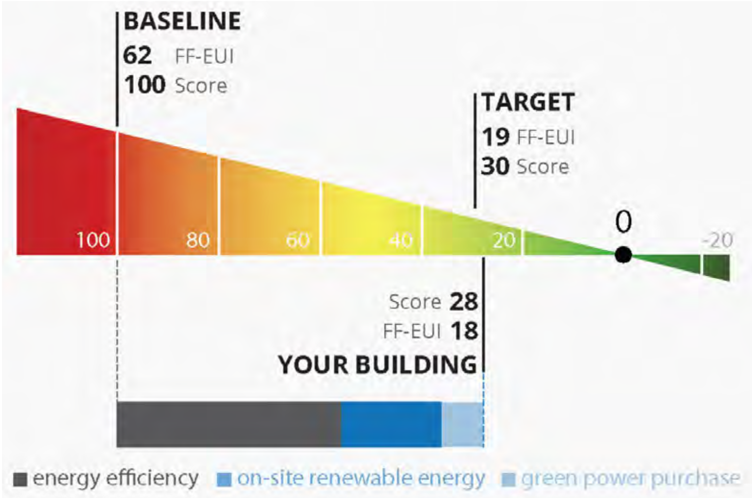

Figure 3: The "Zero Scale" by Arch 2030

During the writing of this paper, Architecture 2030 (2017) released the "Zero Scale," shown in Fig. 3, along with an on-line tool to replace the EPAs Target Finder, a zEPI-like linear scale based on fossil fuel EUI (FF-EUI). It upgrades the previous approach to the 2030 Targets by making clear the role of on-site renewables and sets ZNC at zero. It is, however, not a carbon scale but, rather, a fossil energy scale—for the main reason that it makes no distinctions among the GHG impacts of various fuels. For example, the CO2*e* of grid-supplied electricity and natural gas are treated equally by the surrogate measure of total fossil fuel use.

Dekay and Giddings (2016) showed that because Architecture 2030's guidelines for its influential 2030 Targets allows 0-20% of the fossil fuel reduction target to be met by imported off-site renewables, a confusion can arise about the meaning of the year 2030 "carbon-neutral" target and terms like net-zero energy, site net-zero carbon, etc. The ZNC solves the confusion about the meaning of zero carbon in the 2030 Targets, by allowing on-site or procured renewables to balance the scale. It does not however, allow users an easy way to calculate something comparable to the 2030 targets for fossil fuel use, which is tied to benchmark EUI for a building type and climate, or offer how to extend these into the future. The ZNC/zEPI approach also collapses the distinction between the emissions offset value of on-site renewables, which have no grid losses or transportation fuel consumption, and off-site renewables, which do (See Table 1). This paper and its CBI solve all three of the above problems. The *Carbon Balance Index* allows performance comparison along a spectrum from typical buildings that depend entirely on fossil fuels to those that export energy, comparing a range of carbon performance.

Table 1 Emissions factors for grid-supplied and renewable electricity in the US and Canada
Sources: Environment Canada, Natural Resources Canada, and ASHRAE

CANADA CO_2e EMISSIONS, NATIONAL AVERAGES	
Fuel Type	**Emissions Rate CO_2e lbs / kWh (kg / kWh)**
Electricity, grid displaced	N/A
Electricity, off-site renewable	–0.441 (–0.200)
Electricity, Canada, average	0.441 (0.200)

USA CO_2e EMISSIONS, NATIONAL AVERAGES	
Fuel Type	**Emissions Rate CO_2e lbs / kWh (kg / kWh)**
Electricity, grid displaced	–1.835 (–0.083)
Electricity, off-site renewable	–1.670 (–0.758)
Electricity, USA, average	1.670 (0.758)

Method

Carbon Use Intensity Benchmark

The CBI is a way to compare a building's greenhouse gas production, as CO_2 equivalent (CO_2e) relative to a typical building's *Carbon Use Intensity* (CUI), using EUI data categorized by climate and building type. In the same way that EUI is widely used to describe and compare a building's energy performance, the Carbon Use Intensity (CUI) method was expanded by DeKay and Brown (2014, p 280–291), based on work developed by Bryan (2009). The CUI, with units of CO_2e lbs/ft^2/yr (or CO_2e kg/m^2/yr) is used as the basis to develop the CBI, accounting for the relative impacts of different fuels and renewables on CO_2e. CUI is equal to the building's EUI times a CO_2e conversion factor/s based on the emissions rate of the fuel type/s used. To convert site EUI to Carbon Use Intensity (CUI) multiply by the CO_2e conversion factor:

$$\text{CUI} = \text{EUI} \times CO_2e \text{ conversion factor}$$

EPA's Target Finder tool (2012) gives the typical percentage mix of gas and electricity use for the building's region. These percentages can be used along with the average building EUI to establish a benchmark CUI (Bryan, 2009). "The total CUI is the sum of CUIs for each fuel used. For example, if the building uses some natural gas and some electricity, as many buildings do, then the EUI attributable to each fuel is used to find a CUI for gas and a CUI for electricity and then these are added to get the total building CUI" (DeKay & Brown, 2014, p281). Table 2 shows an excerpt from CUI targets published in *Sun, Wind & Light* by US climate zone and building type. They provide similar calculations for residential and non-residential buildings in the US and Canada, using a variety of emissions factors from EPA, NRC Canada, and ASHRAE.

Table 2. Median Carbon Use Intensity (CUI) targets, USA commercial buildings
CO_2e lbs/ft^2/yr, excerpt of table (DeKay & Brown, 2014)

ASHRAE Climate Zones	City	Small Office 5500 sf / 1st			Medium Office 53628 sf / 3 st			Large Office 498588 / 12 st			Medical Office 40946 / 3 st			Primary School 73960 / 1 st			Secondary School 210887 / 2 st			Hospital (general medical & surgical) 241351 5 st			Senior Care Facility 20025 SF (1)			Hotel (small) 43200 / 4 st		
		med	70%	90%	med	70%	90%	med	70%	90%	med	70%	90%	med	70%	90%	med	70%	90%	med	70%	90%	med	70%	90%	med	70%	90%
1A	Honolulu, HI	25.3	7.6	2.5	35.7	10.7	3.6	42.1	12.6	4.2	57.1	17.1	5.7	18.3	5.5	1.8	28.4	8.5	2.8	82.3	24.7	8.2	49.5	14.8	4.9	25.8	7.7	2.6
1A	San Juan, PR	24.8	7.4	2.5	35.3	10.6	3.5	41.5	12.4	4.1	55.8	16.8	5.6	12.7	3.8	1.3	22.4	6.7	2.2	82.1	24.6	8.2	49.1	14.7	4.9	25.6	7.7	2.6
1A	Miami, FL	25.9	7.8	2.6	36.7	11.0	3.7	43.1	12.9	4.3	62.9	18.9	6.3	13.2	4.0	1.3	25.0	7.5	2.5	84.2	25.3	8.4	51.4	15.4	5.1	27.4	8.2	2.7
2A	Houston, TX	24.5	7.3	2.4	35.3	10.6	3.5	41.3	12.4	4.1	49.8	14.9	5.0	22.1	6.6	2.2	28.4	8.5	2.8	79.2	23.8	7.9	47.7	14.3	4.8	25.4	7.6	2.5
2B	Phoenix, AZ	26.3	7.9	2.6	37.2	11.2	3.7	43.4	13.0	4.3	62.3	18.7	6.2	21.8	6.5	2.2	32.4	9.7	3.2	82.9	24.9	8.3	51.0	15.3	5.1	27.8	8.3	2.8
3A	Atlanta, GA	22.9	6.9	2.3	33.7	10.1	3.4	39.7	11.9	4.0	38.7	11.6	3.9	22.1	6.6	2.2	23.2	7.0	2.3	73.9	22.2	7.4	44.2	13.3	4.4	23.7	7.1	2.4
3B-CA	Los Angeles, CA	18.2	5.5	1.8	28.7	8.6	2.9	34.9	10.5	3.5	24.9	7.5	2.5	19.7	5.9	2.0	16.6	5.0	1.7	67.7	20.3	6.8	37.5	11.3	3.8	17.8	5.3	1.8

Carbon Balance Index Defined

CBI is defined as the designed building's net CUI (after accounting for renewables) divided by the CUI of a typical building, expressed as a percentage:

$$\text{CBI} = (\text{CUI}_{\text{Design}}) \div \text{CUI}_{\text{Typ.}} \times 100\%$$

The task then is to find both the building design's CUI and that of a benchmark building. The CUI_{Typ} can be calculated as described above or found in *Sun, Wind & Light's* "Emissions Targets" chapter. A similar method can be done for any country with median data for building EUI by class and climate.

Calculating CUI for a Building

To estimate the CUI_{Design}, the following steps are recommended (modified from Dekay and Brown, 2014, p289-91):

1) After *selecting CO_2e rates* for each fuel used from emissions factors data for your country or region, *calculate the source CUI for each fuel* by multiplying the site *Energy Demand Intensity* (EDI), which is the energy demand component of site EUI, for each fuel, by the CO_2e emissions rate for that fuel (from step 1), for example natural gas: site $EDI_{gas} \times CO_2e_{gas} = CUI_{gas}$, where, site EDI is in kWh/ft^2/yr (kWh/m^2/ yr), CO_2e is in lb CO_2e/kWh (kg CO_2e/kWh) for the fuel, and CUI is in lb CO_2e/ft^2/yr (kg CO_2e/m^2/yr).
2) *Find the total demand CUI for the building design* by adding together the CUI for each fuel. For example: $CUI_{gas} + CUI_{electric} = CUI_{demand}$
3) *Estimate the emissions savings from on-site renewables,* in CUI units, by multiplying the on-site renewable *Energy Production Intensity* (EPI) by the emissions rate for on-site renewables: $EPI_{on\text{-}site\ RE} \times CO_2e_{on\text{-}site\ RE} = CUI_{on\text{-}site\ RE}$. The emissions for renewables are negative and on-site renewables typically count for more emissions offset than do grid-supplied renewables. To do this step, one must know the amount of energy produces on-site.
5) *Estimate the emissions savings from off-site renewables,* in CUI units, by multiplying the off-site renewable EPI (such as from utility-generated wind power) by the emissions rate for off-site renewables: $EPI_{off\text{-}site\ RE} \times CO_2e_{off\text{-}site\ RE} = CUI_{off\text{-}site\ RE}$
6) *Find the net CUI* by subtracting credits for on-site (step 4) and off-site (step 5) renewable energy from the gross total CUI for the building demand (step 3): $CUI_{demand} - CUI_{on\text{-}site\ RE} - CUI_{off\text{-}site\ RE} = CUI_{design}$

The following additional interpretations apply: A net design CUI = 0 means a carbon neutral building by the *SWL* emissions targets criteria, while a net design CUI < 0 means a "carbon consuming building," which helps offset greenhouse gases generated by other buildings.

The *SWL Tools* spreadsheet (DeKay, 2016) facilitates the calculation of CUI and allows comparison against a benchmark building and reduction targets for carbon, similar to the 2030 Targets for fossil fuel reduction (See Fig. 4).

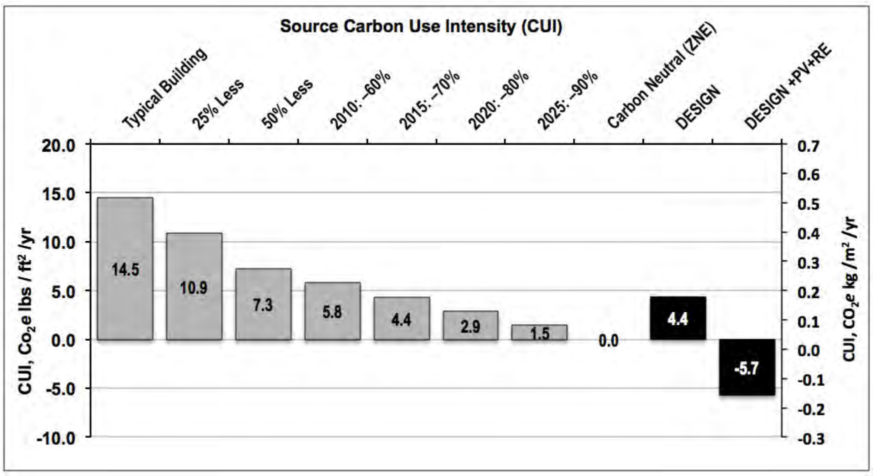

Figure 4. Comparative Carbon Use Intensity (CUI), from *SWL Tools* (DeKay, 2016)

Expanding on the 2030 Targets for Carbon

The CUI_{design} value as described above can then be used to find the Carbon Balance Index (CBI):

$$CBI = (CUI_{Design}) \div CUI_{Typ.} \times 100\%$$

If we take the CUI of a typical benchmark (base) building as a CBI value set at 100 and a zero net-carbon performance (ZNC) as zero, then we can establish a range of targets more or less calibrated to the 2030 Targets for fossil fuel use reduction, as shown in Fig. 5. To do this we have to make an assumption that the zero (ZNC) value includes the 20% allowable off-site renewable energy. While EUI values are commonly published for various base buildings, the CUI is rarely available and must be calculated as described above using the fuel mix and country or regional emissions rates. So, CBI = 100 is *not universal*; rather it is calibrated to local energy supply infrastructure performance, climate, and end use energy mix. With this as a given assumption, we can establish relative reductions in CBI aligned to the targets of Architecture 2030 (80% less fossil fuels in 2020, carbon-neutral in 2030, etc.). The *SWL Tools* spreadsheet workbook (DeKay, 2016) helps to calculate a building's CUI, CBI, and to compare these against various targets. An excerpt is shown in Fig. 6.

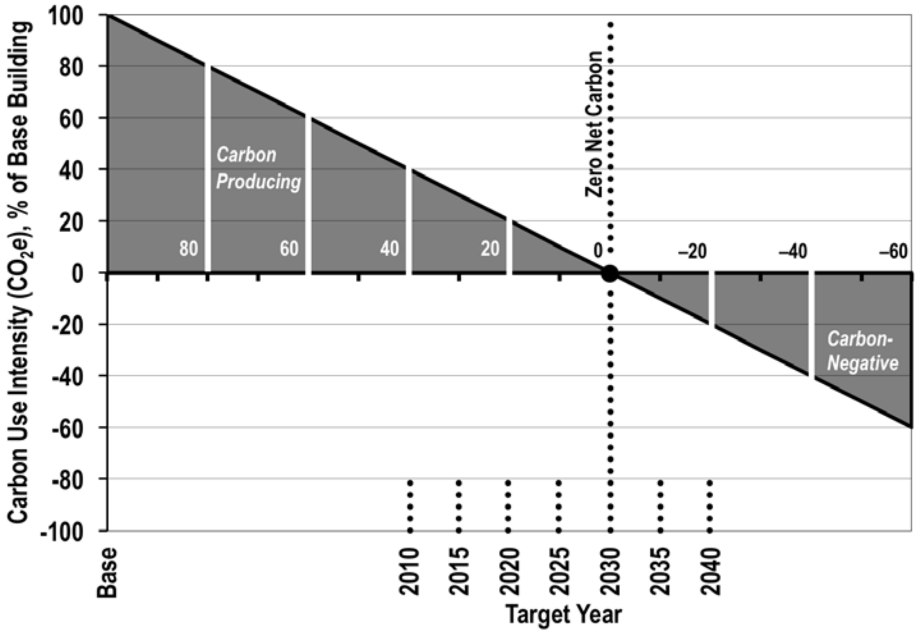

Figure 5. Carbon Balance Index (CBI) Targets

From the 2010 target onward, the targets become a linear progression, with negative CBI targets (carbon-consuming or carbon-offsetting) after 2030. In this manner, CBI = 0 is both "carbon-neutral" in the 2030 Targets schema and "zero net-carbon" in the NBI, et al, definition of ZNC. However, the reader and user of CBI should be clear that, in buildings with a positive CBI (left of zero), depending on the mix of fossil fuel types, the level of energy design for conservation and passive design, and the degree and mix of on-site and off-site renewables, a building meeting the 2030 Targets for a given year, say 2020, may or may not meet the CBI targets shown in Fig. 5. Said another way, a building with a given energy use can produce more or less carbon than a building with the same energy use and a different mix of fossil fuel types and renewable energy types.

CARBON USE INTENSITY TARGETS

Target % Emissions Reduced from Typical Bldg.	Target CUI CO_2e lbs/ ft^2, yr	Targets Achieved?	
Typical Building	14.5	NA	
25%	10.9	NA	
50%	7.3	YES	
60%	5.8	YES	
70%	4.4	YES!	GOOD WORK!
80%	2.9	YES!!	CLIMATE STEWARD!
90%	1.5	YES!!	NEAR CARBON NEUTRAL BUILDING
Carbon Neutral	0.0	YES!!!	CARBON CONSUMING BUILDING!

CARBON BALANCE INDEX: YOUR DESIGN $CBI = (EUI_{des} \div EUI_{typ}) \times 100\%$

[Net] Your Design CUI CO_2e lbs/ ft^2/ yr	Base Bldg. Typ. CUI CO_2e lbs/ ft^2/ yr	Carbon Balance Index (CBI)
(5.7)	14.5	-39.5%

Figure 6. Carbon Use Intensity (CUI) and Carbon Balance Index calculated in *SWL Tools* (DeKay, 2016)

EBI and CBI Compared

Building on earlier work of Dekay & Giddings (2016) on the *Energy Balance Index* (EBI), the CBI and EBI targets, curves and zero points are compared in Fig. 7. The EBI is indexed to the same base building performance in EUI units and a zero value is a site net-zero energy building, meaning that it produces as much energy on-site annually as it consumes. EBI values are negative when the building is a net energy consumer and positive when it is a *plus-energy* building that exports net annual energy. Carbon, on the other hand, is produced by the building's use of fossil fuels and, therefore, has a logically positive value (CBI > 0) to the left of zero when it burns source fossil fuels, while a building is "carbon-negative" (CBI < 0) when it no longer uses fossil fuels for operation and produces renewable energy for export.

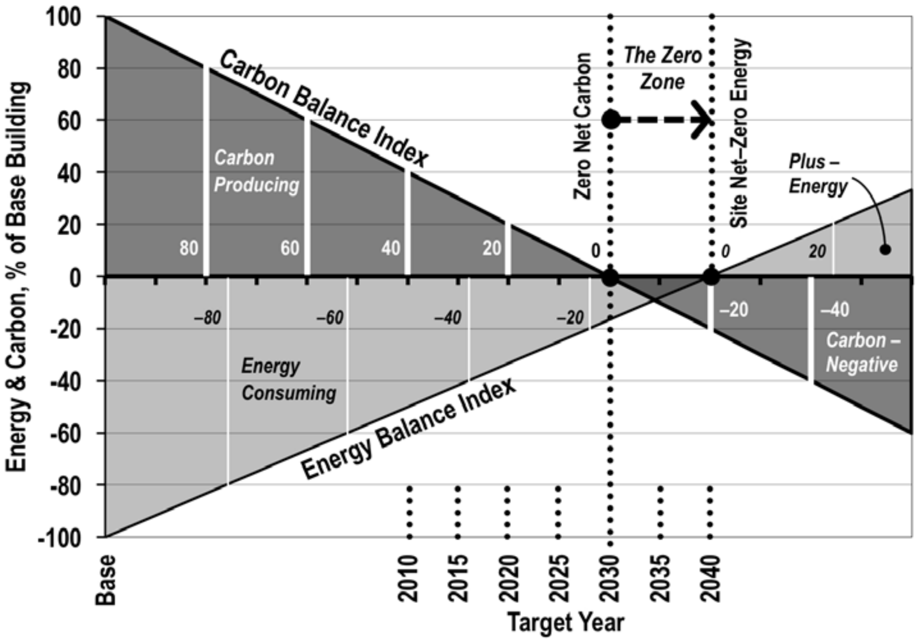

Figure 7. Carbon Balance Index (CBI) and Energy Balance Index (EBI) Targets compared

Therefore, one can see that Figure 7 shows two building performance indices with different definitions of zero. When EBI and CBI are overlaid, an ambiguous "Zero Zone" appears. The difference is in the system boundary. We could set the EBI zero at the CBI zero point, but critics argue that one could simply purchase one's way to zero energy, rather than design and engineer the performance. The distinction of *site net-zero* seems to remain useful, if not necessarily for all buildings. We could similarly move the CBI zero point to align with EBI, with critics arguing for the efficacy of a focus on fossil fuels, rather than where the renewables are sourced. The good news is that if every building operated in the Zero Zone, the climate crisis would be solved by design. Buildings in the Zero Zone would all be high-performance buildings. It is useful to note that if a ZNC building uses no on-site renewables and imported renewables are maxed out at the 20% set by the 2030 Challenge, the only way to further improve CBI and become carbon-negative is to add on-site production.

Findings

With the Carbon Balance Index, carbon-neutral buildings (as defined by the 2030 Challenge) have CBI = 0. Positive CBI means some fossil fuels are used and carbon is produced, while negative CBI projects "consume" carbon by exporting excess energy and offsetting fossil grid energy. Depending on the rate of imported renewable energy, 'carbon neutral' can have a range on the Energy Balance Index (EBI) from 0 to –20.

The paper provides a method to quantify and index CO_2e performance relative to the ZNC definition (and beyond) and relative to the 2030 Target of "carbon-neutral," by using carbon reduction targets in the five-year increment promoted by Architecture 2030 for fossil fuel reduction. The value of the CBI is that it honors and builds on the work of NBI and Architecture 2030 as important driving forces in solving the climate crisis by design, while also giving credit and value to the more impactful emissions offset power of on-site renewables. The CBI, being based in the carbon use intensity (CUI) methodology outlined, also helps with the critical distinction between fossil fuel types on the way to ZNC, and provides a way to fairly assess progress toward and beyond ZNC.

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Tall Buildings: Structure and Energy

Juliana Felkner[1], Josef Schwartz[2], Eleni Chatzi[3]

[1] School of Architecture, The University of Texas at Austin, Austin, TX, USA, email: juliana.felkner@austin.utexas.edu
[2] Department of Architecture, ETH Zurich, Zurich, Switzerland
[3] Department of Civil, Environmental and Geomatic Engineering, ETH Zurich, Zurich, Switzerland

Abstract: To reduce greenhouse gas emissions from the built environment, a holistic approach for energy efficient design over the life cycle of buildings is necessary. Little research exists that simultaneously investigates structural efficiency and energy efficient operation. Therefore, in this paper, we present a framework for considering both the embodied and operational energy in the context of a tall building. For this, we integrate code-based structural design of tall buildings with energy demand simulations and perform a multi-objective optimization in various climate zones. The presented framework is effective at generating the Pareto fronts for structural efficiency, and operational energy (heating and cooling) demand. For a given structural topology, it allows one to determine the most efficient designs with respect to each domain for a given climate. The designer can then a) evaluate how close his or her design is to these efficient designs, and b) make an informed decision as to which design to pursue. By relating operational energy to structural performance, we have introduced a tool that allows one to compare the initial investment of a building (material and construction) to the costs incurred over the lifetime.

Keywords: structural design, energy performance, tall buildings, urban densification, shading, multi-objective optimization

Introduction

The building industry is responsible for roughly one-third of the global energy demand as well as anthropogenic greenhouse gas emissions (Lucon & Ürge-Vorsatz 2014). Considering this relatively large impact, it is necessary to ensure that buildings are designed, constructed and operated in a sustainable manner. At the same time, over 50% of the global population lives in cities (United Nations 2014), poising cities to be the *key to sustainability* (Rees & Wackernagel 1996). As densification of the building stock is inevitable, tall buildings are, and will become, an increasingly important building typology in the future.

For tall buildings, a *premium for height* exists resulting from the exponential increase of the required material to withstand lateral, i.e., wind loadings (Ali & Moon 2007). In recent years, several studies have investigated whether a similar premium exists for energy demand or CO2 emissions, without definite conclusion, mainly due to the prototypical nature of buildings, case study type investigations, as well as the scarce availability of consistent data for comparison (Optis & Wild 2010). One systematic study of a generic tall building found that a) lowest weight does not imply lowest embodied energy (EE), b) reinforced-concrete (RC) frames are more favorable than steel frames from an EE point of view, and c) the flooring system has the largest impact on EE, with RC floors having the least impact of all considered systems (Foraboschi et al. 2014). In fact, it is concluded that considering EE does not impose an additional premium for height, i.e., “sustainable tall building structures can be obtained without modifying the architecture”.

Similarly, the impact that the structure of the tall building has on the overall energy performance has not received significant attention in the scientific literature. In his seminal work, Yeang was the first one to investigate the interaction between the placement of the structural core and energetic performance in tall buildings (Yeang 1999). More recently, Krem et al. have analyzed Yeang’s combinations with preliminary structural calculations, and combined it with energy performance results (Krem et al. 2013). They found that while asymmetric distribution of structural walls may reduce energy consumption by up to 32% depending on the climate zone, it also results in higher torsional stresses and deformations. They concluded that there is a substantial opportunity to optimize structural performance and improve sustainability. However, great care must be taken to ensure that energetic performance does not compromise the structural integrity.

Structural optimization aims at achieving efficient structural performance while at the same time minimizing structural weight under a set of constraints, such as maximum allowed displacements and stresses (Christensen & Klarbring 2008). Since the design space can be quite large, and the optimization problem may be non-convex, e.g., in topology optimization, heuristic optimization methods, especially genetic algorithms have been used successfully, outperforming gradient-based methods (Rajan 1995; Chatzi & Koumousis 2009). Further, interactive approaches have been integrated with heuristic methods to include the designer into the optimization process (Felkner et al. 2013; Felkner et al. 2013; Felkner et al. 2015; von Buelow 2008; Mueller & Ochsendorf 2013).

Despite these efforts, to date, the simultaneous investigation of structural efficiency and energy efficient operation has been largely neglected. Therefore, in this paper we present a multi-objective optimization framework for considering both structural efficiency and operational energy in a tall building. We focus on the operational energy of tall buildings of 20 to 70 stories, with an RC core and RC frame on the perimeter. To avoid torsional effects, we limit the study to a symmetric, square floor plan with a center core. This scheme is capable of balancing conflicting objectives in supporting the decision-making process of the designer.

Optimization Framework

In a multi-objective optimization, there is typically no single best solution that optimizes all the objective simultaneously. Rather, the concept of Pareto-optimality is used. A solution/design is said to be Pareto-optimal if it cannot be improved in one objective without worsening the other, and constitutes with all other Pareto-optimal solutions the Pareto-set. The optimization framework is shown in Figure 1. Matlab is used to investigate numerically the trade-offs between energy efficiency and structural optimization (www.mathworks.com) by generating the Pareto-set using a genetic algorithm.

Sofistik (www.sofistik.de), a commercial finite element (FE) package, is used for structural analysis. The model is generated using the CADIMP programming language, which allowed it to be saved as a text file, which can be manipulated automatically by the optimizer to update parameters, execute the simulation and gather the results. The main advantage of using a commercial analysis tool is the fact that code-based RC structural design is possible. Sofistik calculates the necessary amount of reinforcement for a given structure, and if the resulting design fails to comply with the given design code, a warning or error is issued.

For the energy model, first a base geometry model is created in the 3D modeling environment Rhinoceros (www.rhino3d.com). Then, the parameters to be investigated are designed using the generative plug-in Grasshopper (www.grasshoppe3d.com). Care must be taken to ensure that the structural model in Sofistik and the geometry model in Rhino/Grasshopper are equivalent. Finally, energy demand, is determined using the DIVA modeling plug-in for Grasshopper (www.diva4rhino.com), which provides a visual interface between the Rhino/Grasshopper design environment and energyPlus.

In practice, for our analysis, we define a custom Matlab procedure that takes as arguments the varied parameters, then generates the input file, executes, and retrieves the results for both Sofistik and Rhino/Grasshopper. Finally, it returns the structural and thermal objective values to the optimizer.

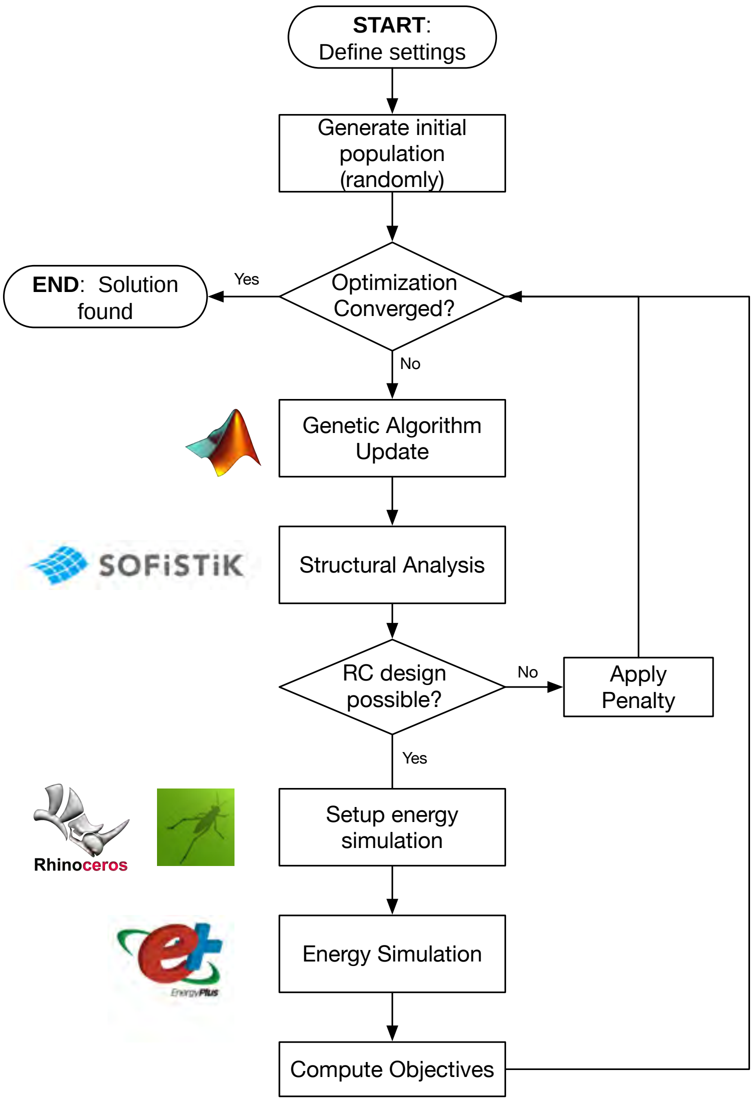

Figure 1: Developed optimization framework

Case Study

We apply the previously introduced framework to analyze the structural design of a tall building. Specifically, we are interested in an exterior wind resisting structure (Ali & Moon 2007), and we investigate how the design of the exterior columns influence the structural performance and the operational energy.

We study reinforced concrete (RC) columns, floors, and walls, suitable for tall buildings with N = 30 stories. Figure 2a) shows a typical floor plan. For simplification, the floor plan is quadratic, and the number of columns on each side is fixed to nine. The core side length is L_c=10m. The side length of the building is $L_b = 2 \cdot 8 + 10 = 26$m, assuming a floor depth of 8m. The wall thickness Tc of the core is defined as follows: For the top ten stories, we set T_c = 20cm, then for every ten stories, T_c is increased by 10cm. Figure 2b) shows the section view of the building. The columns on the periphery are connected via spandrel beams with a constant quadratic cross section of 25 cm side length, creating the exterior tube, and transfer loads to the center core via the floor plates, which have a constant thickness of 25 cm. The story height is set to 3.5m as the average value be- tween typical residential (3m) and commercial (4m) buildings. The resulting Sofistik model is shown in Figure 2c).

To study the influence of column sizes on the structural and energy performance, the Sofistik model is setup as follows:

- We use the Swiss SIA code for reinforced concrete design.
- As load case we define wind loading, acting on one side of the building. The wind zone is set to 2 (reference wind velocity 90 km/h), and the category/class of terrain roughness is set to II (large plain).
- For the materials, we use concrete with a nominal strength of $35N/mm^2$, and reinforcement steel class 500B, with yield strength of $500N/mm^2$, and Young's modulus of $200 \cdot 10^3 N/mm^2$

With this setup, Sofistik performs RC design of the columns, the spandrel beams, the floor plates, as well as the core walls for the ultimate loading. If violations of the building code are found during the design, an error or warning is returned depending on the severity. If the design is feasible, the amount of required reinforcement is returned. For a feasible design, the total mass m of the structure, as well as maximum displacement u_{max} due to wind is extracted. The maximum permissible displacement constraint C is set to $C = u_{max} - H/500$, where H=3.5 x 30 = 105m is the height of the building (Mendis et al. 2007). The structural objective is then $f_s = m \cdot (1 + \max(C,0))$. Structurally infeasible designs are penalized with a large value, and no thermal analysis is performed for them to save computational time.

Figure 2d) shows an example of a floor generated by the Rhino/Grasshopper model. It is created such that the same parameters, i.e., column sizes, can be varied as in the structural model described above. It suffices to consider a single floor without the core structure, which will be considered as a single thermal zone, i.e., office partitioning with individual set-points are excluded. Each of the four sides of the columns are defined as fixed shading components.

The top and the bottom areas of this thermal zone are considered adiabatic, i.e., no heat transfer occurs through them. The remaining four sides are considered fully glazed.

In the thermal/energy simulation, we utilize hourly resolution, and consider the four climate zones humid continental (Boston), humid subtropical (Houston), desert (Phoenix), and temperate (San Francisco). Settings are kept at their default values. The output of the simulation are the annual heating, h_A, and cooling demand, c_A, for one floor, which are then used as heating and cooling objectives.

Denoting by x the width and depth of the columns, the optimization problem is then stated as

$$\text{minimize } [f_s(x), h_A(x), c_A(x)]$$

and solved using Matlab's built in function *gamultiobj*.

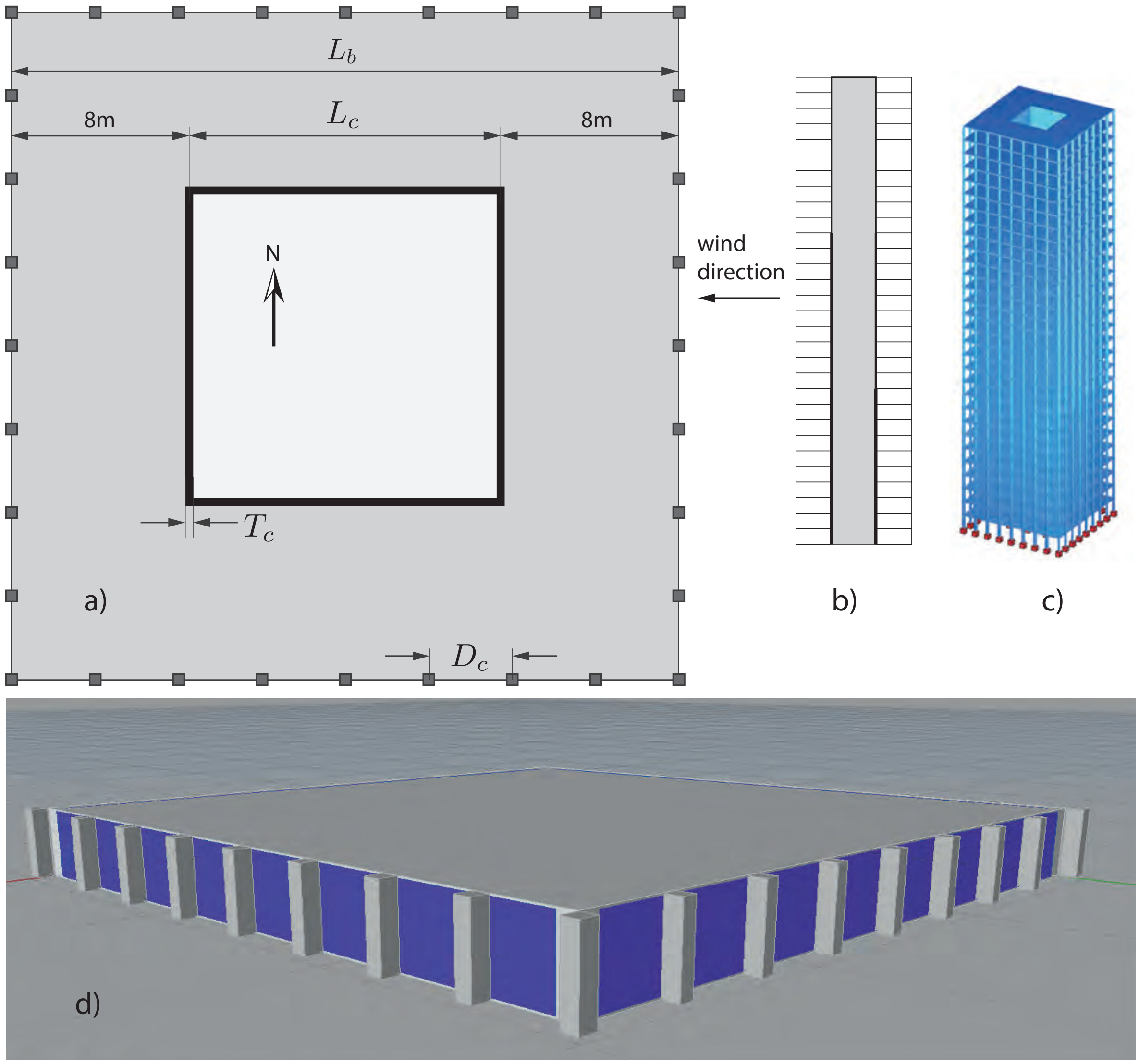

Figure 2 a) Typical floor plan,b) Section view, c) Sofistik model, and d) Rhino/Grashopper model

Results

We normalize both energy demand values with respect to their respective equivalent for the fully glazed case, i.e., when the structure does not act as shading, and show the resulting Pareto-sets as savings in percentage in Figure 3.

In general, we can observe that structure acts as shading, reducing the solar gains in the building. As a consequence, the cooling demand is reduced by up to 50%. The reduction is largest in the San Francisco climate. As for the heating demand, for N=30, the exterior structure acts to reduce some of the heating losses through the window. This demonstrates the trade-offs between structural efficiency and operational energy in different climates, providing the designers with structural variations but also energetic constraints to consider.

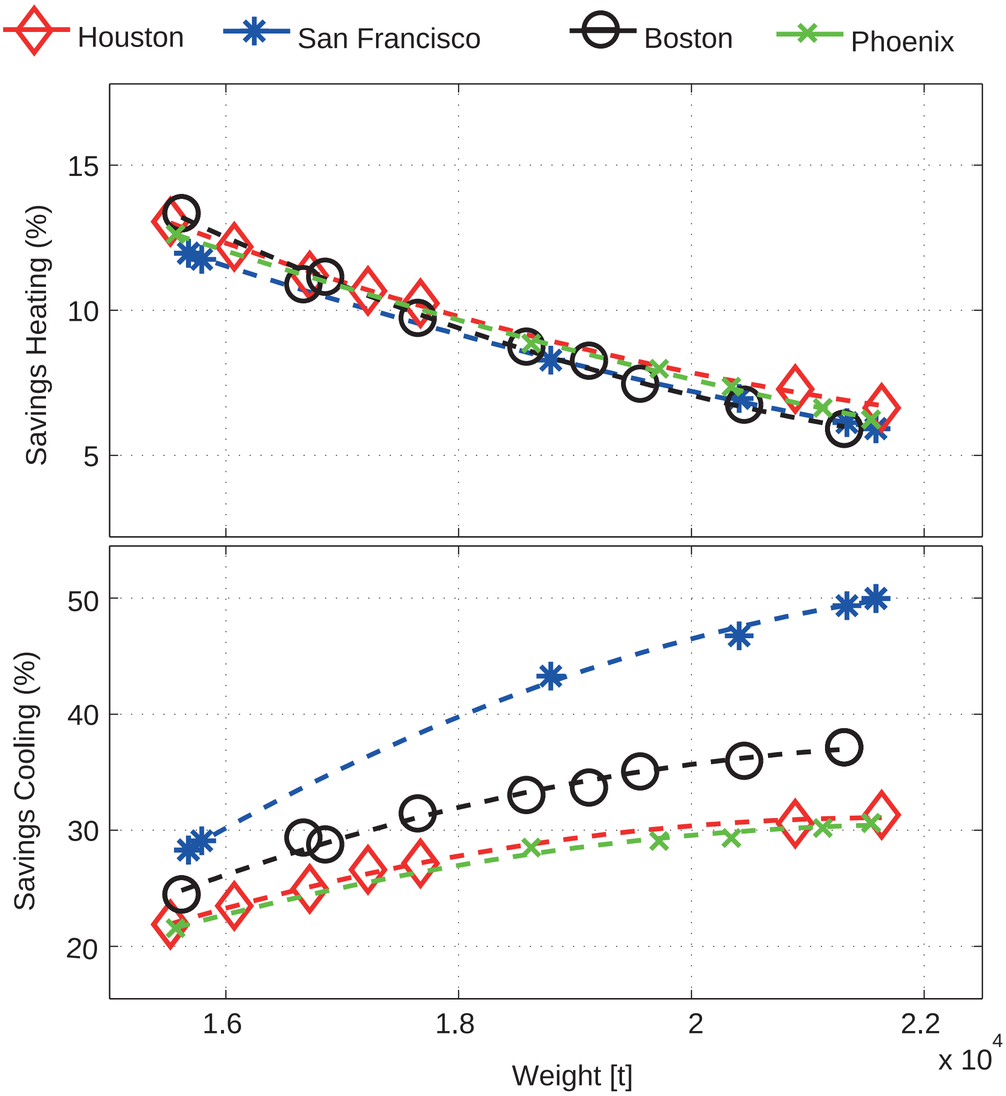

Figure 3 Pareto-sets for the studied climates, showing the trade-offs between structural weight, heating and cooling savings.

As for the column designs, consider Figure 4, which shows again the cooling savings from Figure 3, now with the corresponding columns. We can observe that the optimization framework determined solutions for the whole allowed range from 30cm to 90cm for both the depth and width of the columns in each climate. As mentioned above, every configuration, from the lightest to the heaviest will produce cooling energy savings with respect to the fully glazed facade, and hence should be favored.

The trade-off between operational (cooling) energy and embodied energy (mass/weight) of the building is apparent, as lighter buildings offer less shading, and therefore less cooling savings compared to heavier buildings. This trade-off is more pronounced in the temperate climate, where the cooling savings vary from 28% to 50%. In cooling dominated climates, the trade-offs are less intense, and the savings vary between 22% and 31%. Nonetheless, there is no favor for a specific solution, leaving the architect the freedom of design, while informing him on the trade-offs.

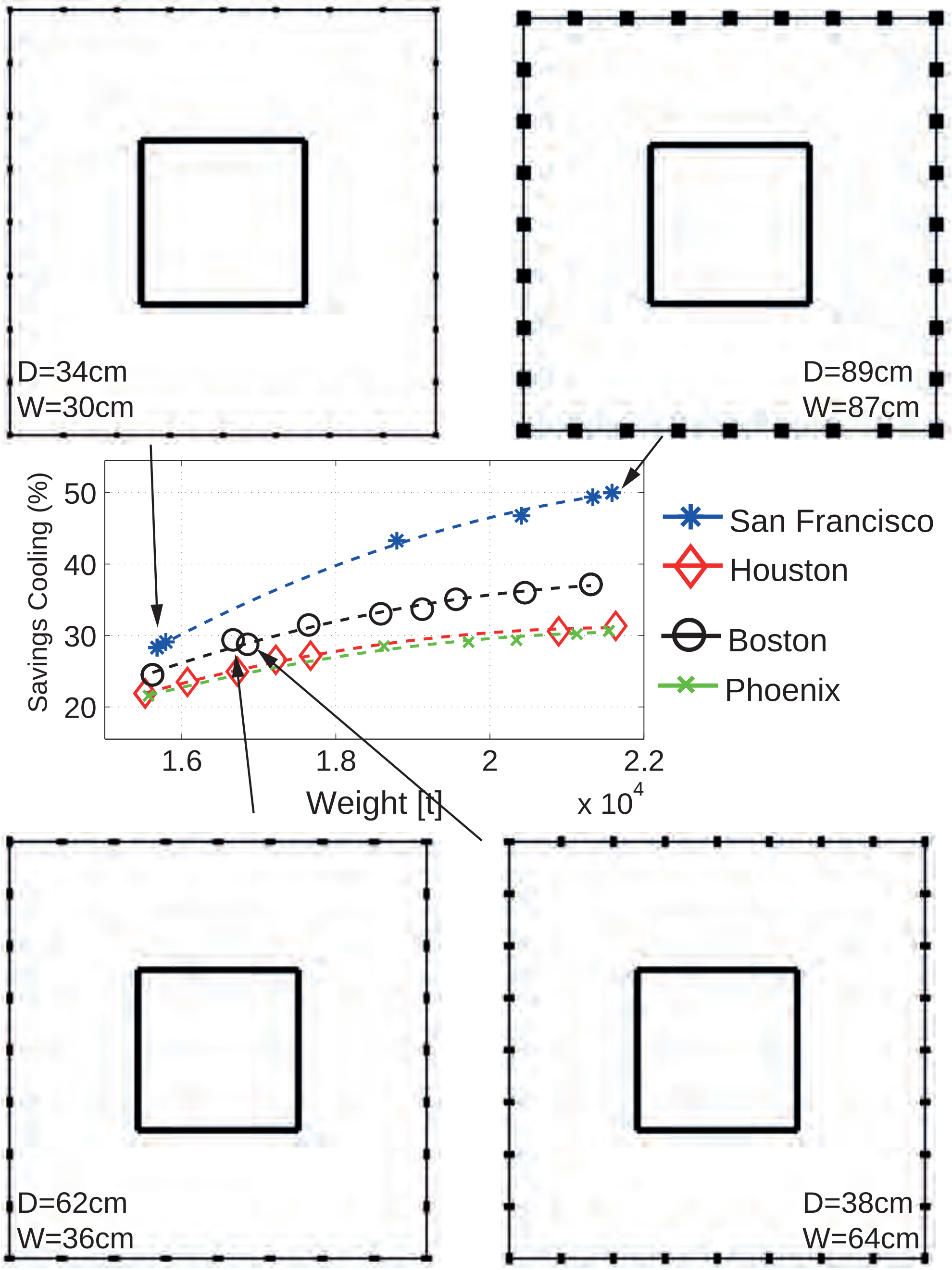

Figure 4: Pareto-set and resulting column structures. The (D)epth and (W)idth of the column are indicated in the individual floor plans.

Conclusion

We have presented an extensible framework for the simultaneous analysis of structural and operational energy performance. Code-based structural analysis is performed using the commercial software Sofistik. Thermal analysis is done using energyPlus through the DIVA plugin for Rhino/Grasshopper. This framework is the first of its kind to successfully combine state of the art structural analysis with operational energy demand. We have applied our framework for the column design of a tall building with 30 stories in various climates, and conclude that in temperate climates (San Francisco), the impact of structure on the perimeter can provide significant savings for both cooling and heating.

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Establishing building environmental targets to implement a low carbon objective at the district level: methodology and case study

Marine Fouquet[1], Thomas Jusselme[1] and Jérémie Vareilles[2]

[1] COMBO Solutions, Lyon, France;
[2] Milieu Studio, Lyon, France

Abstract: To face climate change, greenhouse gas (GHG) emission targets are specified into national policies. In France, the objective is to divide by 4 (Factor 4) the *GHG* emissions by 2050 comparing to 1990. The built environment, as a main contributor, is targeted by these policies: the future 2020 French regulation will set up *GHG* emissions targets for the building life cycle. However, the implementation of this regulation and its labels into real-estate development is challenging because it is uncorrelated to factor 4, architectural and technical constraints due to these labels are yet unknown and targets are defined at building scale and not at the district scale. This paper offers some answers to this challenges based on a case study from a real estate developer who wanted to implement a 2025 objective to a new district in Lyon, France. It was done thanks to a review on Factor 4 and labels' history, on calculation of *GHG* emissions from 1990s building and objectives for 2050 and illustration of labels' constraints. Finally, objectives were allocated at building scale to meet the overall district ambition.

Keywords: Factor 4, labels, low carbon targets, district

Introduction

In the European Union, the construction sector is responsible for 40 % of the energy consumption and for 36 % of the greenhouse gas (GHG) emissions (European Commission, 2017). In 2012 in France, 44.5% of the final energy consumption was due to this sector (SOeS, 2013). Thus, several regulations has been enforced at the European level and at country scales to lower building energy consumption and environmental impacts (Charlier and Risch, 2012). In France, the objective is to divide by 4 (Factor 4) the *GHG* emissions by 2050 comparing to 1990 (MEDDE, 2013). To that end, a new regulation will be implemented in 2020 to specifically reduce *GHG* emissions during life cycle of new buildings (Boyer and Cleret, 2014). Meanwhile, two labels are already available and prefigure the future 2020 French regulation: BBCA (Low Carbon Building label) (BBCA Association, 2016) and E+/C- (Plus energy and low carbon building label) (MEEM, 2016). However, the implementation of these labels into real estate development project faces many challenges:

1. New labels are uncorrelated with the Factor 4 objective, which decreases their communication impact
2. Architectural and technical constraints from labels' targets are not known yet
3. Label's targets are defined at building scale and not at the district scale

This paper suggests answers based on a case study from a real estate developer who wanted to implement a 2025 objective (regarding Factor 4 for 2050) to a district in Lyon, France (11 buildings, around 32 000 m²).

First, this paper reviews how Factor 4 was integrated in regulation and labels, how the latest were built and the existing tools to evaluate performance at district level. Then, the amount of *GHG* emissions of buildings in 1990 and the objective for 2050 are determined using a linear regression. This helps to understand to which year, according to Factor 4 objective in 2050, the labels are corresponding. Similar projects are used to illustrate the architectural and technical constraints of the labels. Finally, objectives are iteratively allocated at the building scale to respect the district overall ambition.

State of the art

The concept of Factor 4 represents the goal of reducing by 75 % *GHG* emissions by 2050 compared to 1990. It represents the reduction that France should target to keep the mean emission per habitant and per year below 0.6 t_{eq} C. This is to meet the objective of a maximal concentration of CO_2 of 450 ppm and limit the average temperature rise to 2°C (Houghton et al., 2001).

Politics around Factor 4 in buildings mainly focus on reducing energy consumption during the use phase (Villot, 2012). However, as energy carriers do not emit the same amount of *GHG* emissions, this strategy does not permit to reduce efficiently the *GHG* emissions. Moreover, a shift of impacts between use stage and construction stage is observed as the decrease of impacts due to heat requirement (thanks to better insulation) is higher than the increase of impacts due to change in materials or construction technique (Blengini and Di Carlo, 2010) Thus, a new regulation and labels (BBCA and E+/C-) are implemented, which directly evaluate the amount of *GHG* emissions during the building life cycle.

In both labels, two different thresholds are imposed. A first one for *GHG* emitted by the building components and equipment (embodied emissions) and a second one for the overall *GHG* emitted along the overall building life cycle. Moreover, different performance levels are available for each labels which are summed up in Table 1 for offices and in Table 2 for apartment buildings (BBCA Association, 2016; MEEM, 2016).

The objective of the BBCA label is to reduce significantly the *GHG* emissions due to the construction products and equipment while the E+/C- label has more a pedagogic objective in order to encourage the Architecture, Engineering and Construction (AEC) industry to evaluate the *GHG* emissions emitted by new buildings.

Table 1: Levels and corresponding threshold for office buildings for BBCA and E+/C- labels

BBCA label		
Levels	Construction threshold [kg eq CO_2/(m².yr)]	Global threshold [kg eq CO_2/(m².yr)]
BBCA (Standard)	11.66	17.66
BBCA Performant	10.06	15.06
BBCA Excellent	9.06	13.06
E+/C- label		
Levels	Construction threshold [kg eq CO_2/(m².yr)]	Global threshold [kg eq CO_2/(m².yr)]
Carbone 1	21	30
Carbone 2	18	19.6

Table 2: Levels and corresponding threshold for apartment buildings for BBCA and E+/C- labels

BBCA label		
Levels	Construction threshold [kg eq CO_2/(m².yr)]	Global threshold [kg eq CO_2/(m².yr)]
BBCA (Standard)	9.08	25.08
BBCA Performant	7.48	22.48
BBCA Excellent	6.78	18.48
E+/C- label		
Levels	Construction threshold [kg eq CO_2/(m².yr)]	Global threshold [kg eq CO_2/(m².yr)]
Carbone 1	16	31
Carbone 2	15	20

Regarding district performances, tools already exist, for instance Sméo (Lausanne and Canton de Vaud, 2014) or the calculation site sheets from (2000 W Society, 2015). However, they require detailed building information which are not necessarily available at urban early design stages. Furthermore, they cannot set up specific *GHG* emissions targets to be included in the building design briefs.

Methodology

Calculation of GHG emissions from buildings in France in 1990 and objectives in 2050

To our knowledge, the objective Factor 4 was not translate into objective for new building expressed in equivalent kilogram of CO_2 emissions per square meter and no study were found about the *GHG* emissions of buildings built in 1990. Nevertheless, the HQE Performance project study the environmental impacts of 24 offices, 17 residential buildings and 22 individual houses were presented (Lebert et al., 2013). This project aimed to identify the biggest impacts' contributor in buildings and the studied buildings are representative for performant buildings in France in 2012. The average impacts from office buildings from HQE Performance are 20.6 kg eq CO_2/(m².yr) and 22.7 kg eq CO_2/(m².yr) for apartment buildings.

Based on the results from HQE Performance, *GHG* emissions from buildings from 1990 are determined for office buildings and apartment buildings considering the fact that energy regulations before 2020 only applied to the use phase and more specifically on energy consumption of heating, cooling, hot water production, ventilation and lighting, also commonly called "regulated uses". In 2012, the objective of energy consumption for this regulated uses were 50 kWh $_{\text{Primary Energy}}$[1]/(m².yr) for office buildings and 57.5 kWh $_{PE}$/(m².yr) for apartment buildings (JORF, 2013) whereas they were around 380 kWh/(m2.yr) for office buildings in 1990 (Manexi, 2012) and around 173 kWh/(m2.yr) for apartment buildings (Shanthirabalan and Rochard, 2014). Moreover, we also assumed that the impacts of construction or other energy uses did not change. Then, these impacts are summed and add to the one of the "regulated uses" from 2012 multiplied by the ratio for energy consumption for this regulated uses between 1990 and 2012. Overall, impacts from 1990s building might be underestimated. Finally, the impacts calculated from 1990s office buildings are 40.7 kg eq CO_2/(m².yr) and 40.6 kg eq CO_2/(m².yr) for apartment buildings.

Then, we divided by four these results to meet the objectives for 2050: 10.18 kg eq CO_2/(m².yr) for office buildings and 10.15 kg eq CO_2/(m².yr) for apartment buildings. Previous work from Switzerland found a target of 12.3 kg eq CO_2/(m².yr) for an office building in 2050

[1] Primary Energy (PE)

(Hoxha et al., 2016). The results cannot really be compared as the context is different (e.g. LCA database) but the order of magnitude is validated.

Labels and corresponding year according to Factor 4 objective

We used linear regression to position the labels' global thresholds according to Factor 4 objective. Figure 1and Figure 2 show the evolution of *GHG* emissions, respectively for office buildings and apartment buildings, which should be followed to reach Factor 4 for new construction in 2050 and the corresponding year for the labels.

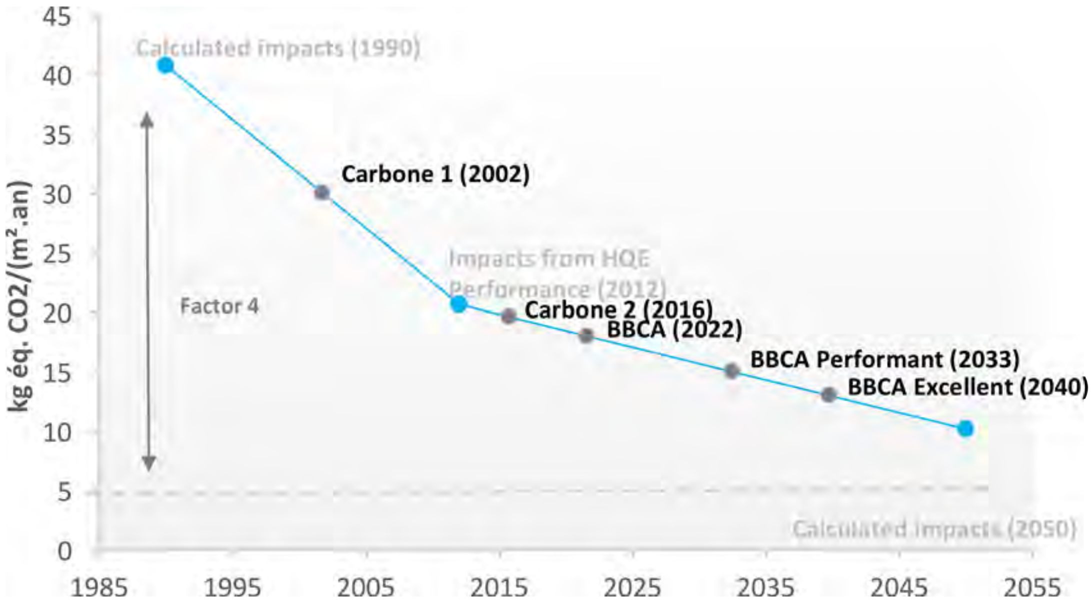

Figure 1: Objectives and labels for office buildings in France

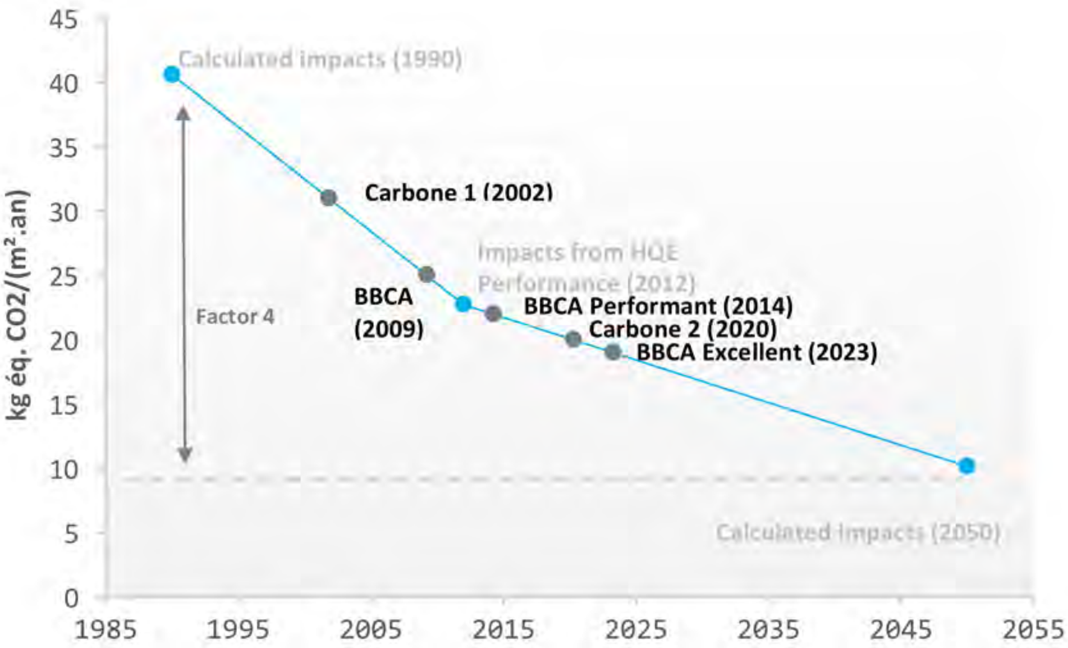

Figure 2: Objectives and labels for apartment buildings in France

For both building functions, improvements through regulations on energy consumption have decreased significantly *GHG* emissions from buildings. Now, the slope is gentlest but the targets for Factor 4 are still ambitious. The different thresholds from the labels are spread and allows the *AEC* industry to choose which performance they want to aim though the labels. Some levels do not even reach today's objective (Carbone 1 & 2 for offices or Carbone 1, BBCA and BBCA Performant for housing). Moreover, labels are more ambitious for offices, 2040 is reached while for apartment building the best year reached is 2023.

Illustration of architectural and technical constraints of the labels

In order to illustrate the technical and architectural constraints induced by the labels, we chose two performant projects, an office building and an apartment building from the same region as the district and built in the past two years. For both projects, detailed information of the construction products, equipment and quantity used were available, even for different construction types for the apartment building. We did not consider underground parking as the district do not have one. As shown by (Lebert et al., 2013), the biggest impacts' contributor in office buildings are the construction products followed by the energy use during the building's life whereas for apartment building, the biggest impacts' contributors are the same but in the opposite order. Therefore, we choose to study different frame structure and energy systems for each project depending on the questions from the real estate developer and choices made by designers. Elodie software (CSTB, 2015) is used to perform the LCAs and the data describing the LCA impacts of construction products are taken for all the scenarios from the INIES database ("INIES, The French EPD Database for building products," 2004).

Our first study is an office building of 8 storages and a total surface of 8 799 m² built in Lyon and compliant with the current French energy regulation : maximum consumption for "regulated uses" of 66 $kWh_{PE}/(m^2.year)$ (JORF, 2013). We evaluated three frame structures and four energy strategies as summed up in Table 3. For each energy strategy tested, the operational energy for the use phase is evaluated annually thanks to French thermal regulation (JORF, 2013). Numerical results for all construction and energy types for the building can be found in Table 3.

Table 3: Embodied and total *GHG* emissions [kg eq. $CO_2/(m^2.yr)$] for an office building for different frame structures and energy systems

	A. Reinforced concrete	**B. Wood facade and reinforced concrete structure**	**C. Wood façade, horizontal reinforced concrete structure and wood-concrete flooring**
1. Water/air heat pump	Embodied : 13.1 Total : 15.6	Embodied : 12.9 Total : 15.4	Embodied : 11.3 Total : 13.8
2. Water/air heat pump without cooling	Embodied : 13.1 Total : 15.3	Embodied : 12.9 Total : 15.1	Embodied : 11.3 Total : 13.5
3. Water/air heat pump and PV panels	Embodied : 13.1 Total : 15.1	Embodied : 12.9 Total : 14.9	Embodied : 11.3 Total : 13.3
4. Gas boiler without cooling	Embodied : 13.1 Total : 19.8	Embodied : 12.9 Total : 19.6	Embodied : 11.3 Total : 18

Results suggest that the choice of materials has an influence on the impact of climate change but not as significant as the energy carrier. However, the impacts for the construction products and equipment are the main contributor of the total *GHG* emissions. Furthermore, compared to the threshold presented in Table 1, Carbone 1 and Carbone 2 are reached easily except the case A+4 (reinforced concrete with a gas boiler without cooling). For the BBCA standard level, lowest GHG emissions than the global threshold are reached in all cases except for cases A+4, B+4 and C+4. However, the thresholds for construction is exceeded for all cases except C+1, C+2 and C+4. Moreover, for cases C+1, C+2 and C+4, the global threshold for "BBCA Performant" is reached but not the one for construction. Regarding our work on Factor 4, objective years reached vary between 2015 (Case A-4) and 2039 (Case C-3).

The second building studied is an apartment building of 7 storages (21 apartments) and a total surface of 1 993 m² built in Ferney-Voltaire and compliant with the current French energy regulation : maximum consumption for "regulated uses" of 63 $kWh_{PE}/(m^2.year)$ (JORF, 2013). Three different frame structures and three different choices for energy were also assessed as illustrated by Table 4. Numerical results for all construction and energy types for the building are summed up in Table 4.

Table 4: Embodied and total *GHG* emissions [kg eq. $CO_2/(m^2.yr)$] for an apartments building for different frame structures and energy systems

	A. Reinforced concrete	**B. Wood**	**C. CLT**
1. 30 % wood boiler/70 % gas boiler	Embodied : 11.4 Total : 21.9	Embodied : 10.9 Total : 21.4	Embodied : 11.2 Total : 21.7
2. 70 % wood boiler/ 30 %gas boiler	Embodied : 11.4 Total : 16.6	Embodied : 10.9 Total : 16.1	Embodied : 11.2 Total : 16.4
3. Heat network	Embodied : 11.4 Total : 19.8	Embodied : 10.9 Total : 19.3	Embodied : 11.2 Total : 19.6

As for the office building, the choice of the energy system seems to be more sensitive than the frame structure but the impacts for the construction products and equipment are the main contributor of the total GHG emissions. Regarding the thresholds from Table 2, Carbone 1 is reached in every scenario while Carbone 2 cannot be reached with the first energy system. For BBCA and "BCCA Performant", for all cases, lowest GHG emissions than the global threshold are reached whereas the maximum construction threshold is overtook. The same conclusion is valid for cases A+2, B+2 and C+2 and level "BBCA Excellent": the overall GHG emissions are lower but emissions for construction are higher than the threshold from the label. Regarding Factor 4 objective, the years reached vary between 2015 (Case A+1) and 2032 (Cases B-2 and C-2).

District case study: iterative allocation of objectives at building scale

For each building of the district (housing or offices) based on their function and their size and on average *GHG* emissions from the HQE Performance project, we calculate the weight of each building in the impact of the district. Some buildings are a mix of different functions so each part of the building is considered separately. The 2012 average performance of the district, based on HQE Performance, should be 692 t eq. CO_2/year. The target of 2025 represents a reduction of 19 % of *GHG* emissions compared to 2012. To reach this objective, iterative targets are set for each building depending on their weight in the impact of the district, the specificity of the program and the architectural ambition. Results are summed up in Table 5 as well as final targeted year for each building and the labels finally reached

Table 5: District building functions, sizes and GHG emissions weights in the district performance based on average from HQE Performance and final targeted year and corresponding label

	Surface [m²]	Storages	Average from HQE Perf. [kg eq. $CO_2/(m^2.yr)$]	Total impact [t eq. $CO_2/(m^2.yr)$]	Weight in impact of the district (%)	Final targeted year	Label
A – Social housing	1529	4	22.7	35	5 %	2019	BBCA Performant
B- Housing	5113	16	22.7	116	17 %	2032	BBCA Excellent
B- Offices	850	16	20.6	18	3 %	2039	BBCA Performant
C - Housing	1061	3	22.7	24	3 %	2019	BBCA Performant
D – Social housing	2019	6	22.7	48	7 %	2019	BBCA Performant
E - Housing	3184	15	22.7	72	10 %	2032	BBCA Excellent
E - Offices	2374	15	20.6	49	7 %	2039	BBCA Performant
F - Offices	756	3	20.6	16	2 %	2019	Carbone 2
G - Offices	3464	6	20.6	71	10 %	2022	BBCA (Standard)
H – Social housing	2120	6	22.7	48	7 %	2019	BBCA Performant
I - Offices	1200	2	20.6	25	3 %	2019	Carbone 2
J - Offices	5048	8	20.6	104	15 %	2022	BBCA (Standard)
K - Housing	1759	5	22.7	40	6 %	2019	BBCA Performant
K - Offices	1284	5	20.6	26	4 %	2019	Carbone 2

Conclusions

This paper shows how to implement low carbon objective at district level based on Factor 4 objective with targets for buildings depending on their characteristics (types, area and number of storeys). First, the amount of *GHG* emissions of 1990s buildings were calculated: 40.7 kg eq $CO_2/(m^2.yr)$ for offices and 40.6 kg eq $CO_2/(m^2.yr)$ for apartment buildings as well as the objective for 2050: 10.18 kg eq $CO_2/(m^2.yr)$ for office buildings and 10.15 kg eq $CO_2/(m^2.yr)$ for apartment buildings. Then, existing labels were positioned according to the Factor 4 objective. Carbone 1 & 2 for offices and Carbone 1, BBCA and BBCA Performant for apartment are late as they do not even reached the current objective. Regarding architectural and technical constraints of the labels, it seems that the energy choice is most sensitive than the frame structure. Finally allocation of objectives at the building scale to respect the objective at the district scale was done with an iterative method depending on the weight of each building in the impact of the district, program's specificity and the architectural ambition.

Further researches will be needed to refine the method and include more characteristics as roof solar potential, compactness and mobility connections for allocation of objective at building scale. Moreover, the development of low carbon buildings will lead to new references which could be used to transform year objectives into example of architectural and energy strategy.

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minLCee Living Lab: a life Cycle energy- and GWP-oriented design case

Vanessa Gomes[1], Marcella R. M. Saade[1], Bruno W. Lima[3] and Maristela Gomes da Silva[2]

[1] School of Civil Engineering, Architecture and Urbanism, State University of Campinas, Campinas, Brazil, vangomes@gmail.com
[2] Department of Civil Engineering, Federal University of Espirito Santo, Vitória, Brazil
[3] Solsticio Energia, Campinas, Brazil

Abstract: Aligned to IEA Annex57 investigation of energy and GHG emissions embodied in buildings, UNICAMP's minLCee Living Lab design shifted focus from operational stage ('net zero') to complete lifecycle. Here we highlight how lifecycle energy and GWP, calculated through CED and CML 2001 v.2.05 methods, enlightened its conception process. Secondary data was collected from literature and manufacturers' brochures, or adapted from existing databases for production cycle modelling in SimaPro 7.3. Energy Plus and Homer Energy software supported operational energy simulation and photovoltaic array sizing. Simulated electricity consumption was 31 kWh/m^2 GFA/year of reference service life. Neutralizing operational electricity plus non-renewable CED of building products was settled as feasibility threshold. PVs would generate 3.6 times the operational electricity and offset 14% of GWP_{LC}. Steel frame, partitions, PVs/BOS and façade panels summed 98% of CED_{PROD} and GWP_{PROD}. Pre-use stages rivaled the operational stage contribution for CED_{LC} (44.5 GJ/m^2 GFA). Contrastingly, GWP_{LC} (7 tCO_{2eq}/m^2 GFA) was dominated by the use stage, from which 91% GWP_{OP} referred to material replacement. For our operational-energy optimized building, the most effective design strategies comprise reducing concrete usage and clinker content, specifying for extended service life and limited material replacement, and prioritizing less transportation-intensive supply chain and EOL treatment.

Keywords: net zero buildings, LCA, low carbon design, CED, GWP

Introduction

The Net Zero concept emerged some years ago as an exciting - and challenging - reference to establish goals and describe success towards aggressive energy use reduction. As only the building operation is considered, the energy input to deliver the building and its components or involved in any other building lifecycle stage is not accounted for. NZ concept also depend on distributed renewable energy generation. From all renewable energy sources, photovoltaic (PV) energy currently shows the fastest growth rate. Considered as one of the cleanest sources of energy available, PV's environmental impacts are basically restricted to manufacturing and disposal (FTHENAKIS; KIM, 2011). Based on the literature reviewed, this embodied impact fraction is seldom acknowledged in neutralization calculations.

The past decades have focused on increasing operational energy efficiency levels. As top operational performance became mainstream, focus has shifted to the proportional share of (grey) energy embodied in the products stage and in end of life processes. Existing databases and much of the literature provide data for the embodied impacts in product stage. In fact, there seems to be a consistent shortage of data across the construction sector on the energy used during all lifecycle stages (MONCASTER; SONG, 2012). Description of transport to site is a big grey area and demands continuous and close interaction with logistics and transport sectors. Prediction of energy use during standard site operations becomes a fundamental part of the whole life embodied energy equation, which has been hampered by a lack of general data on energy intensity of construction equipment and activities, as well as on energy savings related to optimized site management operations. Finally, a clear understanding of the service life of individual components is necessary to support calculations of maintenance, repair, replacement and refurbishment as part of the use stage. There is also limited data on the energy used by demolition, reuse and recycling processes at the end of life of a building.

This paper has the International Energy Agency (IEA) Annex57 as backdrop, which investigated embodied energy and CO_{2eq} in building construction. Motivated by the limited number of publications to support detailed lifecycle energy and green house gas emissions modelling, we describe the procedures and major outcomes from low energy and carbon-oriented design process implemented for (minLCee) Living Lab, designed for the University of Campinas – Brazil. Compensation scenarios beyond operation stage are explored to identify feasibility thresholds and optimize architectural design and specifications.

Purpose and methodological approach

Overview

Building design development and optimization comprised five main parts: (i) developing an integrated design concept for the minLCee; (ii) simulating operational energy (100% electricity) using Energy Plus; (iii) modeling production cycles and the building's lifecycle; (iv) calculation of cumulative energy demand (CED) and global warming potential due to emission of greenhouse gases (GWP) respectively through CED and impact assessment CML 2001 v.2.05 methods, using SimaPro 7.3 LCA support platform; (v) simulating performance of four different PV technologies, using Homer Energy software. This paper focuses on the latter three steps.

Our case study is a 1,005.21 m^2 gross floor area (GFA) building incorporating integrated design process, low-energy and resource use optimization strategies, low-energy aircon system, onsite renewable energy technologies, living roofs and façade, earth construction, storm water management, online resource use and indoor monitoring, among other best practices (Figure 1).

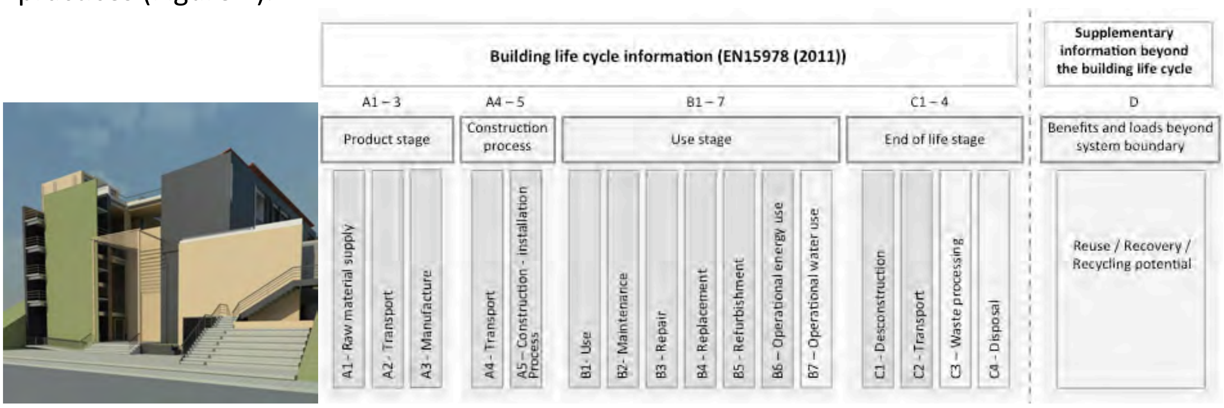

Figure 1 – minLCee Living Lab BIM model. Lifecycle modelling system boundary is shaded over BS EN 15978 (2011) framework for building life cycle information stages and respective modules

The system boundary established for lifecycle modeling in this study spans from 'product' to 'end of life' (Figure 1). Ten neutralization statuses using four different PV technologies were preset, ranging from operational stage (Scenarios 1 to 4) to whole lifecycle

(Scenarios 5 and 5a). Compensation of total operational electricity (net zero) *plus* non-renewable primary energy embodied in raw material supply and manufacturing of building products (NZ(CED) Plus status) was set as design target (Table 1).

Table 1 - Compensation scenarios analysed. Beyond operation (Plus statuses) include building products non-renewable CED accounted for in the Product stage ($CED_{NRen}PROD$). NZ(CED) Plus status [Scenario 4a] was set as design target.

	Compensation Scenarios	PV generation targets
Operation neutral statuses	1. NZ(Emission)	Annual *non-renewable* operational energy consumption (TORCELLINI et al, 2006)
	2. NZ(E) = Net zero energy	Annual operational energy consumption (TORCELLINI et al, 2006)
	3. NZ(CED_{NRen})	Annual *non-renewable* operational CED (Brazilian mix, grid-supplied electricity)
	4. NZ(CED)	Annual operational CED
Beyond Operation (Plus)	1a. NZ(Emission) Plus	NZ(Emission) *plus* $CED_{NRen}PROD$
	2a. NZ(E) Building Plus	NZ(E) *plus* $CED_{NRen}PROD$
	3a.NZ(CED_{NRen}) Plus	NZ(CED_{NRen}) *plus* $CED_{NRen}PROD$
	4a. NZ(CED) Plus	**NZ (CED) *plus* $CED_{NRen}PROD$**
LC	5. LC(CED_{NRen}) neutral	Non-renewable CED *over the building's lifecycle*
	5.a LC(CED) neutral	Total CED *over the building's lifecycle*

Building lifecycle modelling

The CED calculation is based on the method published by Ecoinvent version 1.01 (FRISCHKNECHT; JUNGBLUTH, 2000). CED, expressed in MJ, of each stage of the building's lifecycle was calculated and aggregated for whole lifecycle figures (Equation 1). As implemented in SimaPro (PRÉ, 2008), characterization factors are given for the energy resources in five impact categories, expressed by the renewable (biomass, wind/solar/geothermal and water) and non-renewable (fossil and nuclear) CED components. Lifecycle GWP (GWP_{LC}, equation 2) aggregates GWP calculated for each stage of the building's lifecycle.

$$CED_{LC} = CED_{PROD} + CED_{TR} + CED_{CON} + CED_{OP} + CED_{EOL} \quad \textit{(eq. 1)}$$
$$GWP_{LC} = GWP_{PROD} + GWP_{TR} + GWP_{CON} + GWP_{OP} + GWP_{EOL} \quad \textit{(eq. 2)}$$

Where CED_{LC} stands for lifecycle CED, in MJ, and GWP_{LC} is lifecycle GWP, in tCO_{2e}. PROD is the CED/GWP of extraction/manufacturing of the building products; TR is the CED/GWP of transport activities; CON is the CED/GWP of construction activities; OP is the CED/GWP of operation activities; EOL is the CED/GWP of end of life (EOL) treatment activities.

- **Product stage (Modules A1 and A3)**

CED_{PROD} (in MJ) and GWP_{PROD} (in tCO_{2e}) were calculated by adding all building products consumption (Modules A1 and A3) times their specific CED and GWP per functional unit (kg, m^3 or m^2). Materials and components included in the design were quantified from the construction drawings and bases of design (BODs) documented for the Living Lab, and inventory data sourced for the best possible match. With the exception of concrete (authors' data) and the green roofing system (manufacturer's brochure), materials and components production processes were adapted from Ecoinvent v.2.2 (ECOINVENT, 2010), ELCD v.2.0, Industry Data v.2.0 and US LCI v.1.6 databases (PRÉ, 2008). Ecoinvent database v.2.2 offered information for most items and was preferred for consistency sake, but merging different inventory databases and secondary sources was unavoidable.

- **Construction process stage (Modules A2, A4 and A5)**

CED_{TR} (in MJ) and GWP_{TR} (in tCO_{2e}) of freight transport registered within the supply chain (Module A2) and freight and CDW transport later on in the construction process stage (Module A4) were calculated by multiplying transported mass (in tones) times travel distance (in km) times specific CED and GWP (i.e. per tkm of the fuel and freight modals used) for all building products considered. For estimating CED_{CON} (in MJ) and GWP_{CON} (in tCO_{2e}) of construction activities (Module A5), we multiplied the items/activities considered times their specific CED and GWP per functional unit.

Transported mass and transportation distances were included either accurately, based on actual travel distances, or on best of knowledge estimations, in case of missing information. Data from Ecoinvent v.2.2 and ELCD v.2.0 databases were used for modals and fuel types. The original material mass and corresponding transportation and material usage impacts were corrected using wastage factors derived by Agopyan et al (2003) or observed in actual construction practice. Since the case study is not built yet, construction equipment fuel use was estimated using data for consumption per m^2 of gross floor area (Yan et al, 2010) for a high-rise building in Hong Kong. Even though construction practices may differ significantly from the original context, as well as the fuel intensity for high and low-rise building construction, Brazilian data for construction activities separated from materials usage are not readily available, and a potentially more suitable figure was not found in the literature reviewed.

- **Use stage (Modules B1-B6)**

CED_{OP} (in MJ) and GWP_{OP} (in tCO_{2e}) of the use stage were calculated by adding contributions from maintenance/repair/replacement (Modules B1-B5, i.e. material intake and transportation to the building, as well as corresponding CDW transport to EOL treatment) and operational energy use (Module B6, 100% electricity). Operational energy consumption was simulated using Energy Plus. Data from Ecoinvent v.2.2 (ECOINVENT, 2010) for low voltage electricity in the Brazilian mix were used for operational electricity CED and GWP calculation. Substitution of building products during the building's service life (Use stage, in Figure 1), was planed in accordance with the Brazilian performance standard NBR 15575 (ABNT, 2013), which establishes minimum design service lives (DSL) for major building subsystems. Loads from building parts replacement ('gate to site' freight and corresponding CDW 'site to EOL' transport) were calculated accordingly.

- **End of life stage (Modules C1-C2)**

CED_{EOL} (in MJ) and GWP_{EOL} (in tCO_{2e}) of the end of life stage were calculated by adding contributions from demolition/dismantling equipment energy use (Module C1) and from CDW transport to end of life treatment facilities (Module C2). Two EOL scenarios were considered): (1) demolition as usual (BAU, 0% reuse | 76% recycling | 23%landfill), with 90% of material recovery rate, followed by crushing of concrete, recycling of metals as scrap and incineration of wooden material without energy recovery and landfilling of the remaining CDW; and (2) 90%-recovery efficient selective dismantling (19% reuse | 60% recycling | 20%landfill), followed by partial (40%) reuse of steel frame, crushing of concrete, recycling of steel rebar and 60% of the structural frame and incineration of wooden material without energy recovery and crushing of uncoated glass, and landfilling of the remaining CDW.

Energy demand scenarios and photovoltaic (PV) system modelling

Four crystalline silicon (single-Si, multi-Si) and thin film (amorphous-Si and CIGS) PV technology generations were simulated. Amorphous-Si (a-Si) is the most efficient PV technology from the demanded system power perspective, and could be a good alternative for projects with more surface available; whereas single-Si is the most efficient alternative in terms of area needed to deliver each kWp. PV system sizing procedure using Homer Energy software discounted generation losses to account for *(1)* orientation and exposure angle of the envelope surfaces variation for facade- and rooftop-mounted applications; *(2)* exposure to outdoor temperatures above standard test conditions of 25 ± 2°C (RÜTHER, 2004); and (3) panel ageing. To account for the latter, a degradation factor of 0.5% per year was applied, assuming a 25-year panel service life (LIMA et al, 2012), to ensure that the desired performance is maintained over the whole period of study.

Results presentation and discussion

The minLCee building would consume less than 31 kWh/m^2 GFA per year of reference service life (50 years). Figure 2 shows that offsetting Scenarios 1, 2, 3 and 4 (*i.e.* ranging from the non-renewable portion to total operational electricity CED) is potentially achievable by using all technologies but a-Si, in the latter case. This brings important flexibility to decision-making, particularly in terms of costs and smooth integration to architecture. Considering non-renewable CED embodied in building products in the neutralization targets ('Plus' statuses) basically dismisses surface-intensive PV technologies and single-Si PV stands out.

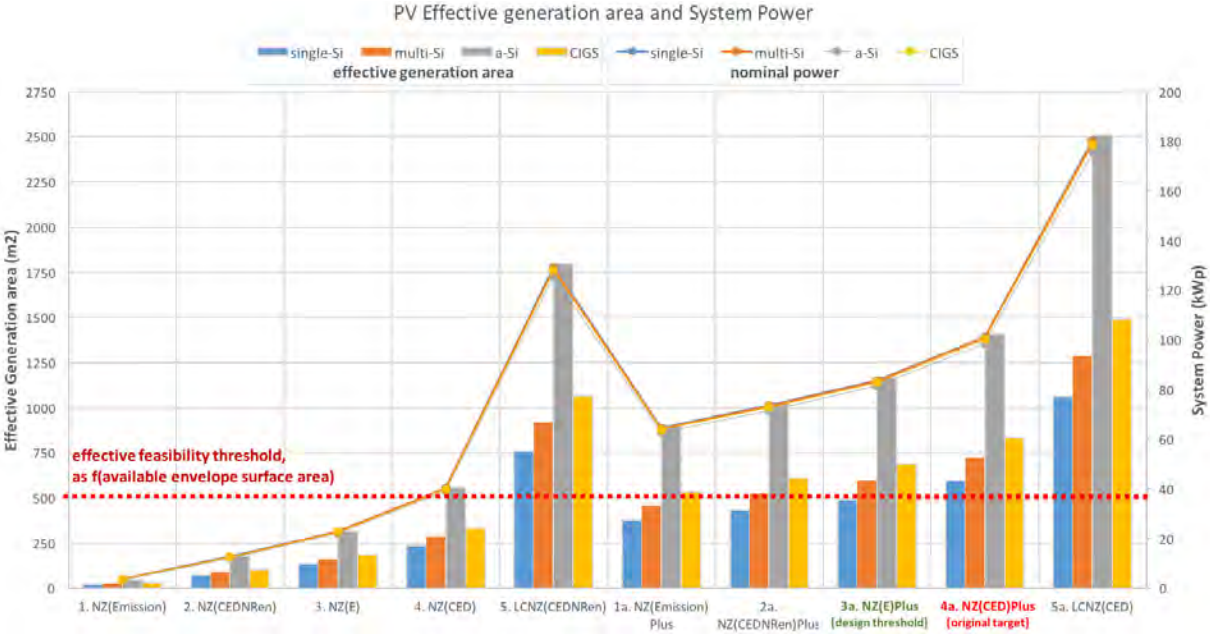

Figure 2 - Energy balance scenarios simulated and respective nominal system power and effective area requirements for the four PV technologies tested. Despite sharing a similar system power profile, effective generation area varied significantly with PV technology. Available envelope area for PV installation ultimately determined the feasibility threshold, to ensure architectural design coherence.

Sizing of the PV array to neutralize operational emissions [NZEmission status, Scenario 1] makes it very evident that such concept does not stimulate progress in contexts with high renewable content electricity mixes, like Brazil. Accounting for non-renewable CED [Scenario 2] instead; achieving 'net zero energy' [Scenario 3] or jumping from that to 'net zero CED' [Scenario 4] would all be goals easily reached through PV onsite generation.

Optimized envelope surface usage for PV mounting while keeping overall architectural coherence ultimately set the practical compensation limit: offsetting the total operational electricity (30,877 kWh/yr) plus the non-renewable CED embodied in Product stage [NZ(E) Plus status, Scenario 3a]. The corresponding installed area of single-Si PV panels was inserted in the building's lifecycle calculations (Figure 3 and Figure 4). The minLCee building would totalize a CED_{LC} of 44.5 GJ/m^2 GFA and a GWP_{LC} under 7 tCO_{2eq}/m^2 GFA. The designed single-Si PV array would generate 3.6 times the simulated operational electricity and offset 14% of GWP_{LC}.

Effective generation area needed by scenarios beyond this threshold exceeded the building's envelope area and would require extra land use, which could be substantial: coping with lifecycle CED demands an effective generation area 98% larger than the building footprint. Nevertheless, CED takes into account the whole energy involved in delivering and using buildings and provides comprehensive and valuable performance description to building professionals, construction and transportation/logistic services and policy makers.

Product modelling (Figure 3) showed that the structural system (steel frame and concrete slabs), partitions (particularly from galvanized steel), the PV system plus BOS, and façade panels contributed to over 98% of CED and GWP embodied in building products accounted for in the Product stage (Figure 4).

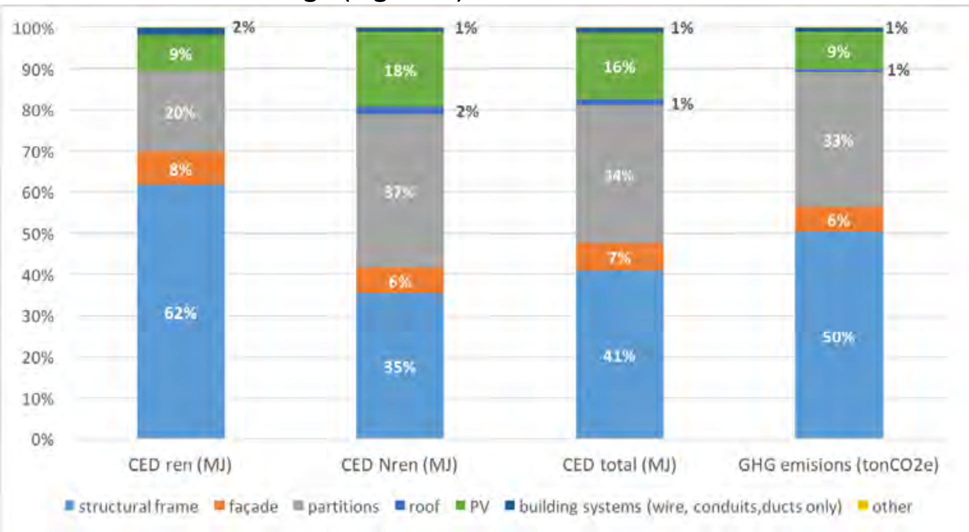

Figure 3 – Major building subsystems contributing to lifecycle CED (renewable and non-renewable) and GWP

Pre-use stages (47%) nearly equaled the use stage (52%) contribution to lifecycle CED (Figure 4), proving their importance in energy assessment of highly efficient energy buildings. Contrastingly, almost 70% of GWP_{LC} refers to the use stage, despite operational energy being mainly renewable. While electricity provision and usage indeed responds for little GWP (8% GWP_{OP}, 44% CED_{OP}), material replacement over the reference service life contributed significantly to operational impacts (91% GWP_{OP} and 56% CED_{OP}). Transportation proportion during the use stage was negligible. EOL treatment also had insignificant effect on lifecycle CED (<1% CED_{LC}) and GWP (<0,1% GWP_{LC}), regardless of the the approach (business as usual demolition or selective dismantling) and material recovery rates combination simulated.

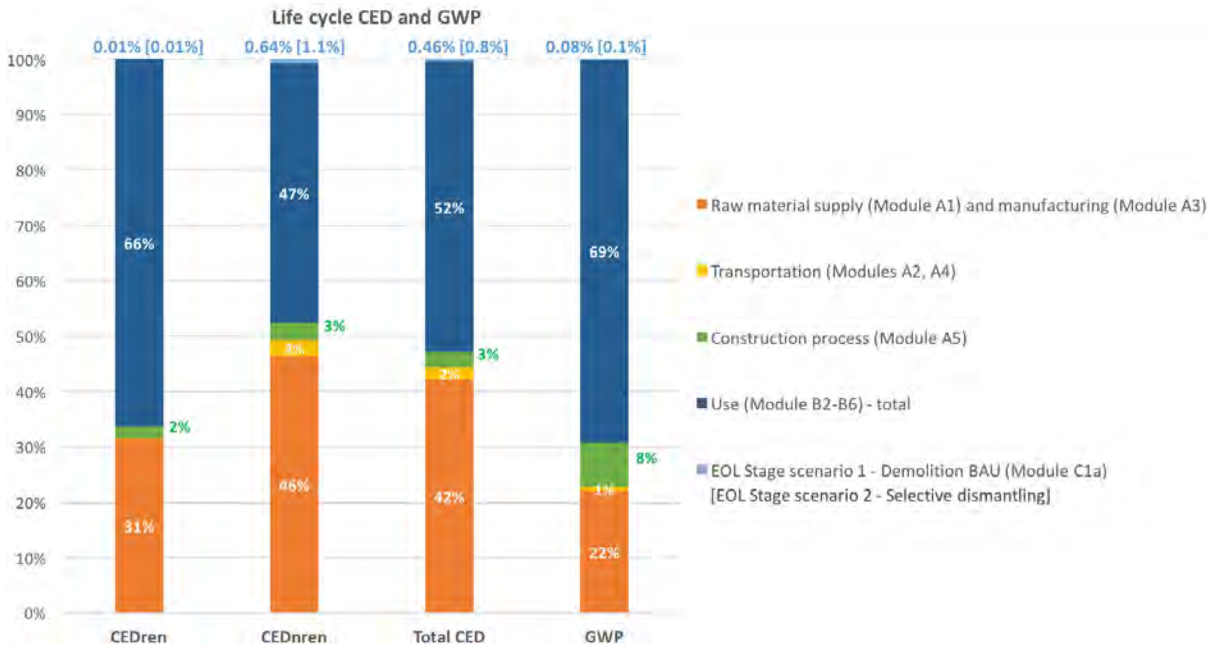

Figure 4 – Contribution to total CED and GWP broken down into building lifecycle stages. EOL treatment had negligible effect, regardless of the scenario simulated.

Conclusions and final remarks

This experience elucidates major gaps and challenges to turn ambitious energy and emissions budgeting goals into mainstream practice in our context. Major takeaways are:

- Once operational energy performance was optimized, the most effective low carbon design strategies for our case study comprised reducing concrete usage and clinker content; specifying for extended service life and limited material replacement/CDW generation; and prioritizing less transportation-intensive supply chain and EOL treatment;
- Replacement rates to comply with a given (or to extend) service life must be carefully analysed. The lack of reliable service life performance data on most building components introduces high uncertainty to a major operational impacts contributor;
- Similarly, material wastage during construction must be also controlled. Though its contribution to GWP is not too high (10%), its CED_{CON} share is important (55%) and so are the respective modelling uncertainties;
- Accounting for benefits of materials EOL attributes (e.g. biodegradability, recyclability) faces modelling limitations. EOL potential can be entered as supplementary information in Module D of the examined cycle, whilst it would be 'harvested' in future lifecycles actually benefiting from reuse/recovery/recycling. Opportunities for CDW to re-enter material cycles within Brazilian construction activities are still limited, and Module D was not included in this study boundaries, which stopped at basic material recovery at the construction site followed by transportation to an EOL treatment facility.
- 'Beginning-of-life' attributes (e.g. renewable, recycled content, local sourcing) are more easily captured within the examined building lifecycle. Renewability net benefit would depend on processing, treatment and transportation profiles, which might not be adequately detected by the two selected impact indicators. Recycled content does play a significant role though, particularly if avoided burden (consequential) LCA

approaches are used, for best capturing such benefit. Finally, prioritizing low transportation-intensive *supply chains* (not only 'local suppliers') can help reducing GWP, in particular, given the predominance of road freight transportation in the country; and

- The product stage allows for attributional LCA application. Consequential (scenario-based) LCA seems to be more appropriate afterwards, given the long service life buildings have, during which a number of technological and contextual changes can occur, and the number of unavoidable assumptions made over the subsequent life cycle stages.

For being a demo building, the maximum generation capacity was basically limited by the available surface for applying traditional rooftop - and façade-mounted PV. The use of BIPV was not explored and could bring further material intake benefits. Ubiquitous use of visible PV panels sends a powerful message for passersby and is tuned with this particular building's mission, but would not necessarily suit other construction types. Furthermore, in real-life implementation studies, cost would still probably be the strongest restriction for aggressive energy and GWP reducing goals.

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How an increase in house size affects the LCA of a bedroom

Iman Khajehzadeh[1] and Brenda Vale[2]

[1] School of Science, Technology and Engineering, Open Polytechnic of New Zealand, Lower Hutt, New Zealand, iman.khajehzadeh@openpolytechnic.ac.nz
[2] School of Architecture, Victoria University of Wellington, Wellington, New Zealand, brenda.vale@vuw.ac.nz

Abstract: Many developed countries including New Zealand have experienced an increase in average house size. Those who living in large houses generally argue that it is just a matter of the initial investment in terms of the financial and energy impact and ignore the long-term resource implications of large housing. The master bedroom has a constant use over the life of a house. The results of a floor plan study of 287 New Zealand houses indicate that with increasing house size the average size of most rooms including master bedrooms also increases. An online survey of 260 owner occupied houses also shows that larger houses with their larger rooms are filled with more furniture. While having spare rooms might be a choice, having a larger master bedroom with more furniture seems to be an inevitable consequence of choosing a larger house. The energy embodied in the construction of a bedroom and its furniture and operation in an LCA study reveals that, for the same function, occupants of larger houses use significantly more energy. This increase in energy for a room with a normal fixed use in different sized houses is generally ignored and needs public awareness.

Keywords: Large housing, Life Cycle Energy, Bedroom, Furniture, New Zealand

Introduction

A QV report (2011) shows the average floor area of new New Zealand houses increased from 112.7 in the 1940s to 128.2 in the 1960s, 142.4 in the 1980s, 194.2 in the 2000s, reaching 205.3 in the 2010s. Statistics New Zealand building consent figures (2014a) confirm this trend. At the same time, Statistics New Zealand (2008) show the occupancy rate of 3.7 in 1951 decreased to 2.8 by 1991 and 2.6 by 2006, and is projected to reach 2.4 by 2031. So on average, fewer people live in larger houses. The same house size pattern is seen in many developed countries, including those in Europe (Dol and Haffner, 2010), the US (United States Census Bureau, n.d), Australia (Fuller and Crawford, 2011), and Canada (Anderson, 2013).

An investigation (Khajehzadeh, 2017) of these new, large houses in New Zealand revealed they have several spare bedrooms (with no usual occupant), double/triple living rooms, double/triple garaging, several bathrooms (including en-suites) and specialised rooms (such as a study, playroom, games room, and studio). People choose large houses for many different reasons, although the extra flexibility of these is the main one (Khajehzadeh, 2017). While some aspects of new, large houses can bring flexibility, others do not seem to help with this. For instance, having an additional room for occasional guests seems useful, since the extra room could also be used as a study or as a sick room when someone is ill. However, having four or five extra bedrooms does not seem particularly flexible. Having a reasonably sized bedroom could give flexible space (somewhere to have a desk, or a quiet place to read) while having a huge bedroom helps less with flexibility and is more a matter of fashion.

Most people think living in a large house is only a matter of initial investment while Khajehzadeh (2017) shows there are future consequences of this initial decision over the life of the house. Larger houses usually have larger rooms of the same type, including bedrooms. As suggested above, an increase in the bedroom floor area seems to offer space for additional functions. However, the same study shows most large houses have a separate study and the bedroom is only used for sleeping. This means that, for the same function (sleeping), larger houses use up to 66% more floor area. This additional floor area is just the outcome of having a larger house and not necessarily something intended by the occupants.

Obviously, a larger bedroom needs more building materials for its initial construction and refurbishment, as well as more energy for lighting and heating over the life of the house. Clause G7 of the New Zealand Building Code (MBIE, 2014) states the window area of a habitable space is at least 10% of its floor area. This means larger bedrooms also need more (or larger) windows to meet the code. Analysed floor plans (Khajehzadeh, 2017) revealed larger bedrooms also have more area for built-in wardrobes, adding to the materials that go into these items, which may be replaced more than once in the life of the house.

Over the life cycle of the house, energy is also required to heat each bedroom. Assuming a similar construction technology for all bedrooms, size of bedroom and its windows have key roles in heating energy. Mithraratne et al. (2007) calculated the annual energy for heating a $94m^2$ light construction house in Auckland using ALF 3.0 simulation software, resulting in an energy use of 2,123kWh/annum for “all day” and 1,768 kWh/annum for “intermittent” heating. A monitoring study by BRANZ (Isaacs et al., 2010) of energy use in New Zealand households shows total national average energy is 11,410 kWh/annum of which 34% (3479 kWh/annum) is for space heating. Isaacs et al. (2010) also compared their results sample ALF 3.0 house simulations and found significant differences. ALF 3.0 predicts whole house heating while their monitoring study shows most households only heat part of the house. They also found differences in length of heating season (months) and daily heating (hours) between their monitoring study and ALF 3.0 simulations (Isaacs et al., 2010). The same BRANZ study also found that in New Zealand homes 45% of space heating energy comes from solid fuel, 32% is electric, 15% gas and 8% LPG (Isaacs et al., 2010). The main solid fuel is wood used in wood burners normally installed in living rooms. This means New Zealanders need another way of heating other rooms, including bedrooms. Personal experience and observation shows that portable gas or electric heaters are used for bedroom heating.

Khajehzadeh (2017) and Khajehzadeh and Vale (2016) found large New Zealand houses, including master bedrooms are filled with more furniture and appliances, and these items normally have a very short life (Treloar et al. (1999) and Vale and Vale (2009)), not only because of wearing out, but also from changes in fashion or technology (Mithraratne et al., 2007). Based on these issues, this paper investigates how the initial decision to buy a large house, with a large master bedroom, might affect the life cycle energy of the house.

Methodology

Floor plan study

As a part of a PhD study on the impacts of house size on occupant behaviour and resource-use, floor plans of 287 New Zealand houses were analysed using AutoCAD 2015-2016. Floor plans were selected from a range of old and new New Zealand houses. All plans were redrawn in AutoCAD 2015-2016 and the overall floor areas of the house and each room were calculated and entered in an excel spreadsheet. Houses were categorised according to the number of rooms following the Statistics New Zealand (2014b) room standard. Full details of this study are available elsewhere (Khajehzadeh and Vale, 2017). An ANOVA one-way test was also conducted in SPSS. This showed the average floor area of master bedrooms is significantly different at 0.01 level ($F_{(5, 272)}$=36.20, p=0.000). The average floor area of the master bedroom in a 4 room house is 14.9m^2 increasing to 16.8, 17.4, 21.2, 23.4 and 27.9m^2 in 5, 6, 7, 8 and 9-9+ room houses. Accepting this, a floor plan of each size of master bedroom was selected from the case study houses and a furnishing plan drawn (bedrooms A to F, Figure 1). The furniture and appliances found in each size of master bedroom are based on a study of New Zealand houses in TradeMe and the survey of owner-occupied houses mentioned above. Full details of both studies are available elsewhere (Khajehzadeh, 2017).

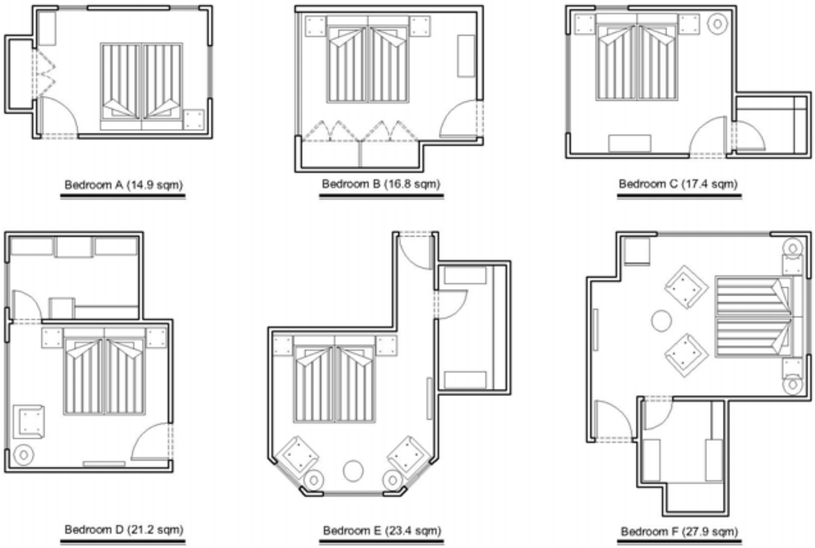

Figure 1 Furnished floor plans of different sized bedrooms from the floor plan study by Khajehzadeh and Vale (2017) (Sources for Bedrooms A-F are respectively Chrystall (1982), McCoy (1956), Navigation homes (2014a), Wood (1993:58-59), Navigation homes (2014b) and Certifiedplans (2016d))

Life cycle assessment of each bedroom size

To simplify calculations, all bedrooms are assumed to be in timber frame houses with timber cladding, which is the most popular construction type in New Zealand (Isaacs, 2015). Mithraratne et al. (2007) conducted a detailed LCA for a typical NZ house, including this construction type. Their study produced the embodied energy per square metre for the different elements of a New Zealand house (Table 1). Based on this and according to the floor area of each bedroom, the embodied energy of each element was calculated for the different bedroom sizes and added to give an overall initial embodied energy (Table 1).

Building elements need maintenance and some need replacement over the life of a house. Mithraratne et al. (2007:130) found very different useful lives for building elements from various sources concluding "there is no commonly accepted useful life for various materials and elements used". This study follows the maintenance schedule of Mithraratne et al. (2007) where the useful lives are an assumed 100+ years for foundation, floor, wall and roof, 60 years for joinery, 50 for electrics and 10 for finishes.

Each bedroom needs lights and over the life of the house, these need electricity to run them and will be replaced at intervals. Accepting a useful life of 1000 hours for each lamp and an average use of 2 hours/day, the overall lamp life is 1 year 4 months. Assuming each lamp costs NZ$1 and has an embodied energy intensity of 1.0MJ/NZ$ (Mithraratne et al., 2007), the embodied and life cycle energy of lamps was calculated and added to the EE and LCE of each bedroom size. Accepting larger bedrooms need more lamps to light them, Table 2 gives the number and Wattage of lamps for each room size and the hours per day each lamp is used. Table 2 also gives the annual electric energy required for lighting each size of bedroom.

Table 1 Embodied energy of elements of a typical NZ house (based on Mithraratne et al., 2007) and relevant embodied energy for similar elements in different sized bedrooms

Bedroom elements	**EE (MJ/m^2) based on Mithraratne et al. (2007)**	**Bedroom size (m^2)**					
		14.9	**16.8**	**17.4**	**21.2**	**23.4**	**27.9**
Foundation	30	447	504	522	636	702	837
Floor	220	3278	3696	3828	4664	5148	6138
Walls	450	6705	7560	7830	9540	10530	12555
Roof	400	5960	6720	6960	8480	9360	11160
Joinery	230	3427	3864	4002	4876	5382	6417
Electric work	100	1490	1680	1740	2120	2340	2790
Finishes	210	3129	3528	3654	4452	4914	5859
Subtotal EE (MJ) bedroom construction elements		24436	27552	28536	34768	38376	45756

Table 2 Number and Wattage of lamps and annual energy for electric lighting of each bedroom size

Bedroom size (m^2)	**Number × Wattage required**	**Hours/day used**	**kWh per annum**
14.9	1 × 100	2	73.0
16.8	2 × 60	2	87.6
17.4	1 × 100 + 1 × 40	2	102.2
21.2	1 × 100 + 1 × 60	2	116.8
23.4	1 × 100 + 2 × 40	2	131.4
27.9	1 × 100 + 1 × 60 + 1 × 40	2	146.0

As noted, bedrooms are normally heated by portable electric heaters for a few hours a day and usually near sleeping time. A time-use study of rooms in New Zealand houses by Khajehzadeh et al. (2016) shows on average New Zealanders spend 8.7 hours per day in each sleeping bedroom. Isaacs et al. (2010) found the average New Zealand heating season lasts for 6 months. Here it is assumed people will heat their bedrooms for 2 hours per day in the evening for 6 months using a portable electric heater. The New Zealand company Aber Holdings Ltd (Kent, n.d.) sell wood fires and portable heaters. They have a guide to selecting a suitable portable heater for the size of room, based on a typical timber frame house with a "tin roof, wooden windows and modest insulation", and an assumed heat loss of 80 Watts per m^2 to keep the temperature at 21 degrees Celsius. Based on this the Wattage required for each bedroom size is calculated using the nearest appropriate size of heater (Table 3).

Table 3 Wattage of portable heater required and energy-use per annum for heating each bedroom size

Bedroom size (m^2)	**Wattage required based on Kent (2017)**	**The nearest available Wattage in market**	**Energy-use per annum (kWh)**
14.9	1190	1200	438
16.8	1340	1300	475
17.4	1390	1400	511
21.2	1700	1700	621
23.4	1870	1900	694
27.9	2230	2200	803

Life cycle assessment of bedroom furniture

Each bedroom needs furniture and appliances and larger bedrooms need more of these (Figure 1). The embodied energy of furniture and appliances was calculated using the cost method developed by Treloar (1998) and previously used by Fay (1999), Mithraratne et al. (2007), Vale and Vale (2009) and Khajehzadeh (2017). It uses an estimated 8MJ/$ for furniture and 10MJ/$ for appliances (Treloar, 1998). Treloar's (1998) values use the Australian dollar although the very small difference between that and New Zealand dollar is ignored here.

Table 4 Furniture and appliances used in each bedroom size, their NZ median price and estimated useful life

Furniture type	Median NZ market price ($NZ)	Useful life (Years)	Number available in each bedroom
Double bed frame	739	25	A-F (1X)
Double mattress	479	10	A-F (1X)
Chest of drawers	500	25	A-C (1X) and D-F (2X)
Free standing mirror	150	25	D-F (1X)
Bedside table/cabinet	170	25	A (1X) and B-F (2X)
Armchair	749	25	D (1X) and E-F (2X)
Coffee table	364	25	E-F (1X)
Vases	89	30	E-F (1X)
Rug	699	15	E-F (1X)
Ottoman/Footstool	364	25	E-F (1X)
Floor lamp	249	20	C-D (1X) and E-F (2X)
Wall clock	32	10	A-F (1X)
LCD/LED TV	1689	10	D-F (1X)
Bar fridge	450	13	F (1X)
Hair dryer	69	8	A-F (1X)
Hair straighter/Hair curler	79	8	A-F (1X)
Electric oil filled radiator	180	10	A-F (1X)

The furniture analysed, replacement schedule, and cost follow Khajehzadeh (2017) (Table 4). The judgement of what to include was based on the survey of owner-occupier households and observations of houses advertised in TradeMe (Khajehzadeh, 2017). For example, the survey shows the average number of bar fridges in 9-9+ room houses is significantly higher than all other house sizes and is almost zero for houses with less than 9 rooms (Khajehzadeh and Vale, 2016). At the same time, images of 9-9+ room houses advertised for sale in TradeMe show some master bedrooms include a bar fridge (Khajehzadeh, 2017).

Results

Following the cost method and useful lives of furniture and appliances, the life cycle energy of building elements and their maintenance, operating energy (heating and lighting) and furniture/appliances were calculated for 0, 25, 50, 75 and 100 years (Table 5). Adding these for each bedroom size gives the overall life cycle energy at each life stage (Table 6). From Table 5, by living in an 8 rather than 4 room house, over 100 years 57% more energy will be used for construction and maintenance of the master bedroom, with a 60% increase in operating energy and 269% increase for furniture and appliances. In a 100 years, by living in an 8 rather than 4 room house, occupants will use 114% more energy for the master bedroom.

Table 5 Life cycle energy (GJ) of building elements and their maintenance, operating energy (GJ) and energy (GJ) required for furnishing each bedroom size at certain life stages

Bedrooms	**Construction and maintenance of bedrooms (GJ)**				
	Year 0	**Year 25**	**Year 50**	**Year 75**	**Year 100**
A	24.4	30.7	41.6	51.3	62.2
B	27.6	34.6	46.9	57.9	70.2
C	28.5	35.9	48.6	60.0	72.7
D	34.8	43.7	59.2	73.0	88.6
E	38.4	48.3	65.4	80.7	97.8
F	45.8	57.5	78.0	96.1	116.6
	Operating energy (GJ)				
A	0.0	46.0	92.0	138.0	184.0
B	0.0	50.6	101.3	151.9	202.5
C	0.0	55.2	110.4	165.6	220.8
D	0.0	66.4	132.8	199.2	265.6
E	0.0	74.3	148.6	222.9	297.1
F	0.0	85.4	170.8	256.2	341.6
	EE and LCE of furniture and appliances (GJ) at various house life stages				
A	18.7	46.3	79.9	107.5	141.1
B	20.1	49.0	84.0	112.9	147.9
C	22.6	54.0	91.4	122.9	162.8
D	50.6	127.1	226.4	302.8	404.6
E	71.2	167.6	293.1	390.1	520.6
F	75.7	176.6	311.1	417.1	556.6

Table 6 Embodied and life cycle energy (GJ) of each bedroom size at certain life stages

Bedrooms	**Subtotal life cycle energy of each bedroom at various life stages**				
	Year 0	**Year 25**	**Year 50**	**Year 75**	**Year 100**
A	43.1	123	213.5	296.8	387.3
B	47.7	134.2	232.2	322.7	420.6
C	51.1	145.1	250.4	348.5	456.3
D	85.4	237.2	418.4	575	758.8
E	109.6	290.2	507.1	693.7	915.5
F	121.5	319.5	559.9	769.4	1014.8

Figure 2 shows the share of building elements, operating energy and furnishing over the life cycle of a small (14.7m^2) and large bedroom (23.4m^2), revealing more than half (57%) of the total energy of the former (in year 0) goes into building elements while the share of furniture (43%) is also considerable. As the house ages, for a small bedroom, the share of its building elements and their maintenance decreases and operating energy gradually increases, while after year 25 the share of furniture/appliances remains relatively constant (Figure 2). After 25 years, for a small bedroom operating energy is 37.4% of total life cycle energy increasing to 43.1%, 46.5% and 47.5% after 50, 75 and 100 years.

To see how this pattern differs for a large master bedroom, the life cycle energy breakdown of the master bedroom of a small house (Bedroom A) was compared to that of a large house (Bedroom E) (Figure 2). As seen, the energy for furnishing the latter in year 0 is a significant 281% more than the former. In addition, furniture and appliances form a larger proportion of the overall energy of the large bedroom in year 0 compared to the small one (65.0% against 43.4%). This means the impact of furnishing a large bedroom is more than its building, as the energy for the former can be almost double that required to build it. Over the life cycle of the house, the share of operating energy becomes important in both bedrooms. The key difference is that furniture/appliances are more important in larger bedrooms while operating energy is more important in small bedrooms.

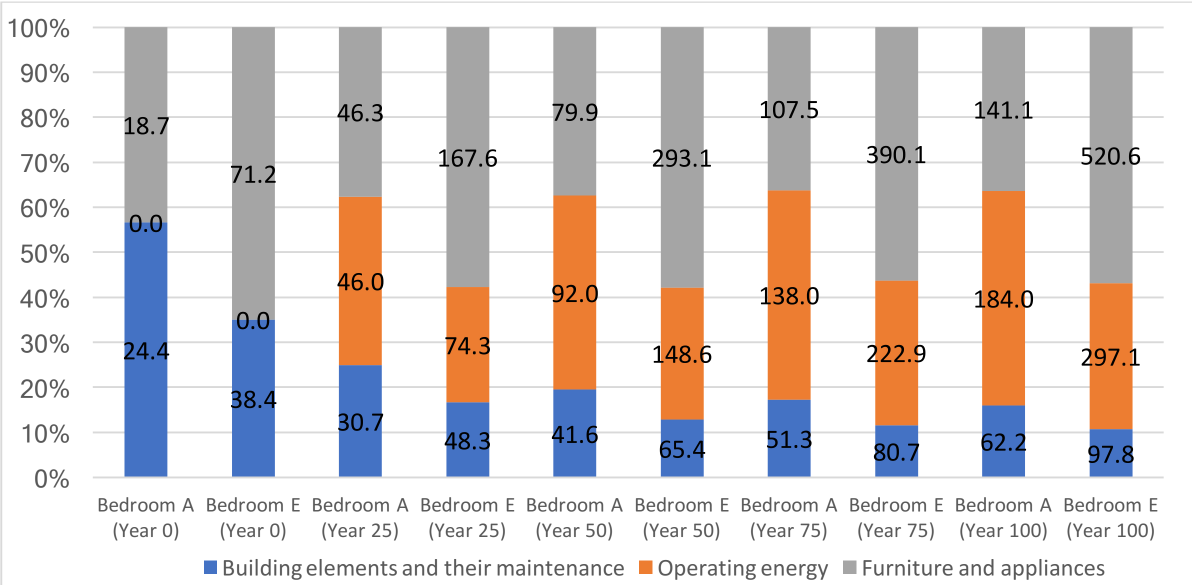

Figure 2 Breakdown of life cycle energy of a small (A) and large (E) master bedroom at various life stages

Conclusion

This investigation indicates that by choosing to live in a large house rather than a small house, the energy required for construction, maintenance, operating and furnishing master bedrooms is increased by 182% in year 0 and 162% in year 100. This becomes more important given that both large and small master bedrooms are designed to fulfil the same function. Results of the New Zealand time-use survey 2009-2010 by Statistics New Zealand (2011) shows New Zealanders aged 12+ daily sleep 8.8 hours, which is very similar to the average bedroom use of 8.7 hours/day found in the survey noted above. This means that almost all the time spent in a master bedrooms is for sleeping and so size does not matter a lot. Most increase in the life cycle energy of larger bedrooms comes from furnishing and heating and lighting these spaces, something most people do not consider when they buy a large house. Perhaps more public awareness is required to familiarise people with the future consequences of living in large houses. In addition, this study show that furniture and operating energy are the important components of the life cycle energy of a master bedroom so it is important to reduce these uses of energy. This means having better insulated houses, including retrofitting the uninsulated housing stock, and making more use of durable and second hand furniture items.

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Design to Thrive

The share of furniture and appliances in the life cycle energy of New Zealand houses

Iman Khajehzadeh[1] and Brenda Vale[2]

[1] School of Science, Technology and Engineering, Open Polytechnic of New Zealand, Lower Hutt, New Zealand, iman.khajehzadeh@openpolytechnic.ac.nz
[2] School of Architecture, Victoria University of Wellington, Wellington, New Zealand, brenda.vale@vuw.ac.nz

Abstract: New Zealand houses comprise various outdoor and indoor spaces. Apart from the resources used for the construction of these, the occupants need furniture, appliances and tools (FATs) to make these spaces liveable. Because FATs have a short replacement time, the life cycle energy of these over the life of the house becomes significant. Different levels of each are needed to support the intended function and so the energy embodied in these for each space is also very different. Additionally, the time occupants spend at home both indoors and out differs significantly. The results of an online survey of 538 New Zealanders living in owner-occupied houses in summer show that while private outdoor spaces are used for an average of 0.55hour/day, bedroom, living room, kitchen and laundry are used for 8.7, 2.9, 1.1 and 0.1hour/day. Less used spaces, such as kitchen, laundry and garden, need a lot of energy for furnishing them and hence, their energy-use may not be as efficient as it might be. In terms of house resource-use efficiency, sharing facilities could lead to a more sustainable use of resources. This paper shows how sharing gardens, kitchens and laundries in a form of co-housing could be a key parameter in reducing the life cycle energy of a house.

Keywords: Life cycle assessment, Sharing, Furniture, Appliances, New Zealand

Introduction

A life cycle assessment study of New Zealand houses by Khajehzadeh (2017) indicates furniture, appliances and tools (FATs) form a significant proportion of the initial life cycle energy of New Zealand houses. For many reasons, including technological improvement and fashion changes (Mithraratne et al., 2007), furniture and appliances have short lives (Treloar et al. (1999) and Vale and Vale (2009)). This means the share of FATs in house life cycle energy becomes more important over the life of the house (Khajehzadeh, 2017).

A survey of 260 owner-occupied New Zealand houses by Khajehzadeh (2017) shows that with the exception of single person households (who have significantly fewer FATs than other household types), the number of people living in a house does not affect the number of FATs. The same study clearly shows that house size has a significant impact on number of FATs in a house (Khajehzadeh, 2017). Regardless of how many people live in a house, some core FATs are required for any household size. For example, a couple with 2 children and a single person household would be expected to have a fridge, stove and washing machine, although the energy required to make and run these is divided by 4 for the former and 1 for the latter. This suggests the number of people sharing certain resources may be key in their sustainable use.

The type of FATs in a space or room reflects the activity expected there (Canter and Lee, 1974). In other words, it is possible to group furniture and appliances according to room types. For example, appliances such as stove, fridge, freezer or dishwasher, which are associated with eating, are usually kept in a kitchen. This makes it is possible to measure the share of various rooms in the overall energy used for furnishing a house.

Results of a summer-based time-use study of 538 New Zealanders living in owner-occupied houses show they spend an average of 15.94 and 0.55hour/day at home indoors and at home outdoors (Khajehzadeh and Vale, 2016a) with 8.7, 2.9, 1.1 and 0.1hour/day spent in bedroom, living room, kitchen, and laundry (Khajehzadeh et al., 2016). Assuming the occupancy rate of 2.65 people per house based on census 2013 (Statistics New Zealand, 2014), the resources that goes to furnishing each of these rooms are not being used effectively.

Obviously sharing private rooms like bedrooms and even bathrooms is not acceptable but sharing spaces that might be considered less private could be. For example, neighbouring houses could share certain spaces, which is similar to but not the same as cohousing (McCamant and Durrett (2011) and Sanguinetti (2012)). Agreement over which spaces can be shared is both a personal and cultural matter that is outside the scope of this study.

Census 2013 indicates that there are more 6 room owner-occupier houses than other sizes in the New Zealand housing stock. At the same time, Statistics New Zealand (2014) shows that 56.2% of 3 bedroom houses (the usual 6 room house) are occupied by 1-2 usual residents. This means that the resources bound up in less-used spaces are shared between 1-2 people. Based on this, this paper aims to investigate how sharing the less private spaces (i.e. laundry, kitchen and garden) of 6 room house with more than 2 people can decrease the overall life cycle energy of a house.

Methodology

As a part of a PhD study, an online survey was undertaken from February to April 2015 using the web-based service Qualtrics (Qualtrics, 2015) to investigate the features of New Zealand owner-occupied houses including their FATs. The survey was limited to small households (single person households, childless couples and couples with 1-2 children) and owner-occupied houses to make sure the FATs belong to the normal occupants.

The questionnaire asked about occupants, type/number of rooms and type/number of FATs in the house. Overall 445 households took part in the survey of which 260 (58.4%) finished the FATs section. In total, 131 FAT items that were most likely to be found in New Zealand houses were covered in this survey. Full details of this survey, associated investigations, and results are available elsewhere (Khajehzadeh, 2017).

The embodied energy of each of the 131 FAT items was calculated using the cost based method developed by Treloar (1998). This method is based on an estimated 8MJ/$ for furniture and 10MJ/$ for appliances (Treloar, 1998) with the minor difference between the Australian and New Zealand dollar being ignored. Using the median price of each item based on main New Zealand suppliers and the useful life of various items (Mithraratne et al. (2007), Fay (1999), Blanchard and Reppe (1998), FannieMae (2014), Fiol (2013), Mr. Appliance (2016), Statista (2011), InterNACHI (2016), Brown (2011), Welch and Rogers (2010), Demesne (2010), Seiders et al. (2007), Cooper (2004), New Zealand Inland Revenue (2015)) the life cycle energy of each item was calculated. Based on the number of each FAT in each sample household (from the survey) and the embodied energy from the cost based method, the embodied and life cycle energy of FATs for each household at various life stages (0, 25, 50, 75 and 100 years) of the house were calculated.

Table 1 Furniture, appliance and tool items found in kitchen, laundry and garden of 6 room New Zealand houses, with median NZ price, useful life, and average number of each

Furniture/appliance/tool type		Average no. in 6 room houses	Median price ($NZ)	Useful life (years)
Kitchen appliances	Fridge/Freezer	1.09	1749	15
	Fridge	0.04	1299	13
	Freezer/Chest freezer	0.35	1200	11
	Oven	0.69	2199	15
	Dishwasher	0.81	1300	12
	Cooktop/Hob	0.54	1500	17
	Stove/Range	0.43	2199	15
	Microwave	0.85	328	9
	Blender/Mixer	0.96	169	8
	Sandwich maker	0.66	69	8
	Slow cooker/Rice cooker	0.76	100	8
	Electric frying pan	0.26	109	8
	Bread maker	0.32	279	8
	Juicer	0.21	270	8
	Popcorn maker	0.21	60	8
	Coffee maker	0.41	255	8
	Food processor	0.65	280	8
	Toaster	1.03	150	8
	Waffle iron	0.21	115	8
	Electric jug	0.96	130	8
Laundry appliances	Ironing board	0.82	80	10
	Drying/Airing rack	1.09	30	8
	Washing machine	1.01	1299	12
	Dryer	0.71	975	14
	Iron	0.90	129	8
Garden furniture and tools	BBQ	0.65	679	10
	Outdoor umbrella/gazebo	0.46	298	10
	Outdoor dining/picnic table	0.57	238	10
	Outdoor chair/couch	2.60	166	10
	Outdoor coffee table	0.15	82	10
	Swing seat/hammock	0.18	250	10
	Sun lounger/recliner deckchair	0.31	219	10
	Trampoline	0.13	314	8
	Slide	0.12	240	20
	Swing	0.13	109	20
	Paddling pool	0.21	29	6
	Lawnmower	0.66	549	8
	Leaf blower	0.18	199	10
	Hedge trimmer	0.24	178	10
	Water blaster	0.28	544	10
	Work bench	0.59	75	10
	Drop saw	0.19	399	10
	Drill	1.13	248	10
	Weed eater	0.60	234	10
	Chipper	0.16	999	10
	Chain saw	0.41	279	10

The survey houses were grouped according to their size, the latter being based on the number of rooms. The number of rooms follows Statistics New Zealand (2014) definitions. It includes all habitable spaces (with floor area more than $4m^2$) enclosed by walls, floor and ceiling/roof excluding all service areas (bathroom, laundry etc.). The kitchen, living room and dining room are counted separately even where these are combined. Based on this, the average energy used for furnishing different sizes of New Zealand owner-occupied houses can be found. On average, a 6 room owner-occupied New Zealand house needs 154.5GJ energy in Year 0 and 325.2 at Year 25, 538.3 at Year 50, 738.8 at Year 75 and 951.5 at Year 100 for furnishing the whole house, including replacing FATs as necessary.

Because of the popularity of 6 room houses, this house size is used here for further analysis. The average number of FATs found in the garden, kitchen and laundry of 6 room houses was extracted from the survey (Table 1). Table 1 also gives the Median price of each item in New Zealand and the estimated useful life for each item from the previously noted references.

Using the cost based method (Treloar, 1998) and the useful life of each item, the embodied and life cycle energy of items kept in kitchen, laundry and garden were calculated separately for the life stages of the house. It is then assumed that with appropriate design adjacent houses can share a kitchen, laundry and garden and the FATs in these spaces. The idea of sharing these spaces is not new. The idea of the 'kitchenless' house was put forward at the turn of the 20th century as a step in the emancipation of women (Hayden, 1981). The shared garden for food growing is often common in less developed countries (Hill, 2011) and is also promoted for social cohesion in developed ones (Veen et al, 2016). The laundrette (coin operated public laundry) first appeared in the UK in the middle of the 20th century (BBC, 2010). Rather than building purpose designed co-housing it would be possible for adjacent houses, or even houses in the same street, to share more, whereby one house has the communal kitchen, one the common laundry and gardens are redesigned to have communal areas for food growing, play, and entertainment.

The energy embodied in building a shared larger kitchen and eating area should be less than building the same spaces for each house, but this has been ignored in this study which is only focussed on the life cycle energy related to FATs and their replacement. The additional assumption is that the operating energy of the shared spaces is not more than the equivalent operating energy of the non-shared spaces. It might be possible to convert existing houses to provide these common facilities but this is also outside the scope of this paper. The aim here is to see whether the savings in life cycle energy from sharing make such design attempts worthwhile.

To see how sharing these spaces might affect energy-use in individual houses, different scenarios of sharing were considered. With proper design it would be possible for all or one or two of kitchen, laundry and garden to be shared with 2-3 neighbouring houses. Table 2 presents 14 possible sharing scenarios. For example, in Scenario 1 a kitchen is shared between two houses while in Scenario 14, a kitchen, laundry and gardens are shared by three houses. Energy savings from each scenario, were calculated and compared to the same house with no sharing to see the impact of various levels of sharing on the life cycle energy of a house.

Table 2 Scenarios for sharing kitchen (K), laundry (L) and garden (G) by 2 or 3 houses

Scenario	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Spaces shared	K	K	L	L	G	G	KL	KL	KG	KG	LG	LG	KLG	KLG
No. of houses sharing	2	3	2	3	2	3	2	3	2	3	2	3	2	3

Results

Following the methodology described earlier and the items listed in Table 1, the embodied and life cycle energy of the average FATs kept in the kitchen, laundry and garden of a 6 room NZ house was calculated for various life stages (Table 3). As seen, the embodied and life cycle energy for furnishing a kitchen is several times that of a laundry and garden.

Table 3 Embodied and life cycle energy of furniture and appliances kept in kitchen, laundry and garden

Spaces	Embodied and Life Cycle Energy (GJ) at various life stages				
	Year 0	Year 25	Year 50	Year 75	Year 100
Kitchen	80.4	199.6	365.8	540.0	666.7
Laundry	22.0	60.5	92.6	151.8	197.7
Garden	25.8	81.0	157.6	206.1	289.9

Using the levels of sharing set out in Table 2 the energy saved by each scenario at various life stages is presented in Table 4.

Table 4 Energy saving (GJ) in each scenario at 5 life stages

Life stages	Energy saving (GJ) in each scenario (S)													
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14
Year 0	40.2	53.6	11.0	14.7	12.9	17.2	51.2	68.3	53.1	70.8	23.9	31.8	64.1	85.5
Year 25	99.8	133.1	30.2	40.3	40.5	54.0	130.0	173.4	140.3	187.1	70.7	94.3	170.5	227.4
Year 50	182.9	243.9	46.3	61.7	78.8	105.1	229.2	305.6	261.7	348.9	125.1	166.8	308.0	410.6
Year 75	270.0	360.0	75.9	101.2	103.0	137.4	345.9	461.2	373.1	497.4	178.9	238.6	449.0	598.6
Year 100	333.4	444.5	98.9	131.8	144.9	193.2	432.2	576.3	478.3	637.7	243.8	325.1	577.2	769.5

These energy savings were compared to the overall energy required for furnishing the whole of an average 6 room house of 154.5GJ in Year 0 and 325.2 in Year 25, 538.3 in Year 50, 738.8 in Year 75 and 951.5 in Year 100 (Khajehzadeh, 2017). The percentage energy savings from each sharing scenario were then calculated (Table 5). Figure 1 presents the percentage energy savings for each scenario for Year 0 in descending order from greatest to least savings.

Table 5 Energy saving as a percentage of the overall energy required for furnishing an average 6 room house for each scenario (S) for certain life stages

Life stages	Energy saving as a percentage of the overall energy required for furnishing an average 6 room house for each scenario (S)													
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14
Year 0	26.0	34.7	7.1	9.5	8.3	11.1	33.1	44.2	34.4	45.8	15.5	20.6	41.5	55.3
Year 25	30.7	40.9	9.3	12.4	12.5	16.6	40.0	53.3	43.1	57.5	21.7	29.0	52.4	69.9
Year 50	34.0	45.3	8.6	11.5	14.6	19.5	42.6	56.8	48.6	64.8	23.2	31.0	57.2	76.3
Year 75	36.5	48.7	10.3	13.7	13.9	18.6	46.8	62.4	50.5	67.3	24.2	32.3	60.8	81.0
Year100	35.0	46.7	10.4	13.9	15.2	20.3	45.4	60.6	50.3	67.0	25.6	34.2	60.7	80.9

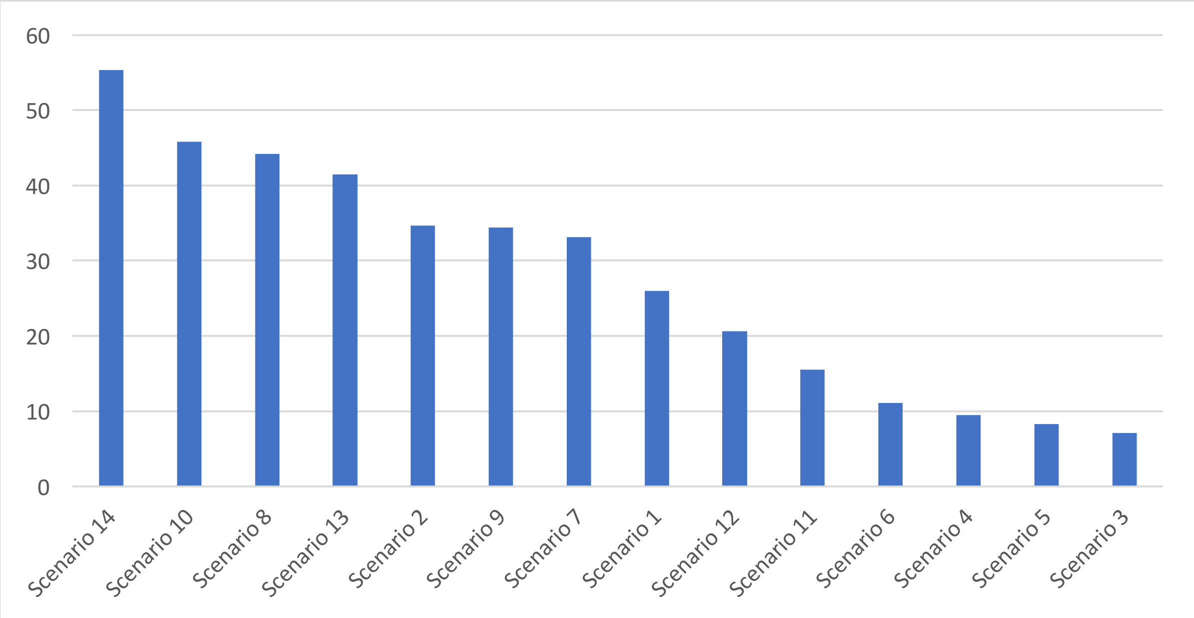

Figure 1 Percentage energy saving (in Year 0) from each sharing scenario in descending order

Discussion and conclusion

A significant part of the energy used for housing goes into furnishing the house. Because FATs have short lives, the energy impact of these increases significantly and becomes more important over the life cycle of the house. On the other hand, people spend little time in some parts of their houses and so the energy embodied in these parts is not used efficiently. In particular, a time-use study of rooms and spaces of New Zealand owner-occupied houses shows that New Zealanders spend little time in the kitchen, laundry and gardens of their houses. Accepting that sharing these might not be acceptable to all people, this study tried to consider different scenarios for sharing these spaces and the effect of this on house life cycle energy.

This study shows the embodied energy of FATs usually found in a kitchen is several times that of laundry and garden FATs in Year 0, although the life cycle energy of FATs becomes significant in all three spaces over the whole life cycle of the house. This study also found the two key parameters for saving energy through sharing were the type of shared space and number of houses sharing. An earlier study by Khajehzadeh and Vale (2016b) shows that number of people sharing a facility is the key parameter in the success of shared spaces and usually spaces shared between smaller groups are more successful. Following this, this study assumed up to three houses could share a kitchen, laundry and garden or any combination of these. This assumption gave 14 sharing scenarios.

As could be predicted, more households sharing a space means more energy savings. While sharing all of the selected spaces produces energy savings the kitchen is the key space when it comes to sharing, as all seven top scenarios for energy saving include a kitchen. In reality sharing a kitchen could be more problematic than sharing a laundry or garden, as many people at the flat sharing stage discover. However, for extended families or very good friends a shared kitchen may be less of an issue. The open plan family kitchen/dining/entertaining space as found in many new houses is also a model for what such a shared space might be like. As could be predicted, the best scenario for energy saving is three houses sharing a kitchen, laundry and garden and in this scenario, each house/household will save 85.5GJ in year 0 compared to a house with no shared spaces. This energy saving increases to 227.4GJ in Year 25 with 410.6GJ in Year 50, 598.6GJ in Year 75 and 769.5GJ in Year 100.

While there is as yet no study on what domestic spaces New Zealanders might be prepared to share it is probable that sharing the garden and laundry would be much more acceptable for most people. With 3 houses only sharing the garden and laundry, each house/household will save 31.8GJ in Year 0, increasing to 94.3GJ in Year 25, 166.8GJ in Year 50, 238.6 in year 75 and 325.1GJ in Year 100. This equates to 20.6% of the overall energy required for furnishing the whole house in Year 0 or respectively 29.0%, 31.0%, 32.3% and 34.2% of the other house life stages.

Sharing only a laundry with 2 other houses, only gives an energy saving of 14.7GJ in Year 0, increasing to 40.3, 61.7, 101.2 and 131.8GJ after 25, 50, 75 and 100 years. These savings are respectively 9.5%, 12.4%, 11.5%, 13.7% and 13.9% of the overall energy required for furnishing the whole houses at the same life stages. Sharing only a garden between 2 houses saves more energy than sharing a laundry (17.2, 54.0, 105.1, 137.4 and 193.2GJ after 0, 25, 50, 75 and 100 years, or 11.1%, 16.6%, 19.5%, 18.6% and 20.3% of the overall energy required for furnishing the whole house). As seen, though these savings are not as big as from sharing a kitchen, they are still worth consideration.

This study also shows the energy saved from sharing the kitchen, laundry and garden of an average 6 room house between 3 houses is 55.3% of the overall energy required for furnishing the whole 6 room house in Year 0, 69.9% in Year 25, 76.3% in Year 50, 81.0% in Year 75 and 80.9% in Year 100. Even following scenario 1 where 2 households share a kitchen, the saving is 26.0% of the overall energy for furnishing the average 6 room house in Year 0, and 30.7% in Year 25, 34.0% in Year 50, 36.5% in Year 75 and 35.0% in Year 100. This is important as while designers fill the kitchens of modern houses with more and more luxurious fittings and appliances, studies show that many people are not cooking at home anymore (Smith et al., 2013). This questions the need for a private kitchen for all houses given the significant energy saving that comes from sharing this particular space of New Zealand houses.

What will affect all these results is the acceptability of the concept of sharing in New Zealand. A further study is required to understand what is and what is not acceptable for New Zealanders when it comes to sharing domestic spaces, and who people would be prepared to share these space with, given they are appropriately designed for easy sharing.

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Towards Near Zero Energy in High Density Residential Areas

Olga Kolodiy and Guedi Capeluto

Faculty of Architecture and Town Planning, Technion – Israel Institute of Technology, Haifa, Israel

Abstract: The aim of this work is to check the feasibility and limitations of near ZERO Energy design in highly dense conditions. The study is carried out by examination and comparison of various density design alternatives of an existing urban plot in the coastal climate zone of Israel. In this paper, we introduce design alternatives that increase on plot residential units' number by about 200%, compared to existing plot conditions (Kolodiy and Capeluto 2016). Increased dwelling units' number leads to higher energy use on the one side and mutual shading of new high rise residential buildings on the other, and then present to us new challenges. Preserving solar rights within the plot borders and outside for PV systems installation become more complex. The relations between urban density and passive solar urban design, energy consumption and energy production within plot borders are presented and discussed.

Keywords: Zero energy. Urban density. Photovoltaics. Solar energy. Energy consumption.

Introduction

Carbon dioxide is considered one of the major components of all greenhouse gases responsible for climate change. The buildings sector is responsible for about 30% of total world carbon emissions and other greenhouse gases (UNEP, 2009). In Israel, the electricity consumption by all buildings sectors accounts for about 60% of the total consumption (Ministry of National Infrastructures, 2010), and almost 50% of total greenhouse gasses are emitted by buildings (Teshner et al., 2012). Nowadays, with more than 8 million inhabitants, about 90% of Israel's population lives in urban areas (Word Bank, 2015). The increasing urban population and current lifestyle will lead to the growth in households' number and urban areas densification. As a result, the energy consumption and greenhouse gases emissions will grow, as well as mutual environmental influences between buildings. To reduce the construction industry's negative effects on the environment, buildings should minimize their energy consumption and become energy producers. This industry has the highest potential for immediate action with economic benefit and long-term effects of significant reduction in greenhouse gasses emissions.

Previous studies of urban zero energy districts (Marique et al., 2013) (Hatchem et al., 2012) are concentrated on single family houses or relatively small apartment buildings which does not match new Israeli minimum density requirements. Generally, studies of zero energy feasibility for high-rise buildings (Cho and Kim, 2015) relates to a single building and does not refer to challenges as mutual shading or variable buildings' orientations.

Previous study results

In a previous study (Kolodiy and Capeluto, 2016) the existing condition of the case study plot was examined in terms of zero energy design feasibility. The plot is located in Tel Aviv – Jaffa (32.5N, 35E), one of the densest cities in Israel. It includes twenty-one, four-storey height residential buildings. These buildings were built in early 50`s, when the construction speed was more important than quality. Each building is composed from 22 housing units.

The first stage of the study was to determine on plot buildings' energy consumption. Two conditions were checked: existing condition with no envelope insulation, and improved, which included envelope insulation improvements according to Israeli Energy Rating of Buildings Standard (ST 5282-1, 2011). In addition, a densification alternative of two floors addition above the existing buildings was checked.

The second stage was to examine potential buildings envelope surfaces for photo voltaic (PV) array installation. It was found that roof is the preferable surface for PV system implementation, while horizontal turning of the PV array is most suitable for the examined urban situation. Although, the energy production of a horizontally placement method is slightly lower than ideally south oriented PV panels with 30° tilt, it can be suited to any building orientation and aesthetically integrated, creates minimum shading on neighbouring buildings if rises above rooftop.

According to the study, there is a direct relationship between urban density, energy consumption and area needed and available for electricity production. As the density grows, total energy consumption rises and less well exposed areas are available for PV systems implementation due to the bigger shading areas caused by the higher buildings. Thus, passive solar design principles are important as much as energy efficient envelope design to approach the goal of near zero energy buildings. To make the PV systems worthwhile in dense areas, passive solar design must to be implemented on urban level as much, as in building design. The study showed that even near zero energy goal is difficult to achieve using less effective, 12% efficient PV panels array implemented on the roofs. Existing buildings' protrusions and balconies, limits PV array installation on main facades.

For this case study using low efficiency PV panels, 50% energy generation within building borders should be a realistic target. However, currently more effective solar panels, from 16% to more than 20% efficiency, are available. Moreover, in 2014, a 4-junction solar cell with 46% efficiency was announced (Tibbits et al, 2014). It takes less high-efficiency panels to generate the same amount of energy as more low-efficient panels. In addition, less area is required for more efficient PV array installation, which brings us closer to the goal of zero energy.

Under this scenario of more efficient solar panels, it is theoretically possible to achieve Zero Energy goal for the existing plot situation with improved envelope using solar panels roof installation with about 30% efficiency. When plot density increased (addition of 2 floors), more efficient panels are needed. Zero Energy for this condition will be possible to achieve with 40% efficient PV panels (Figure 1).

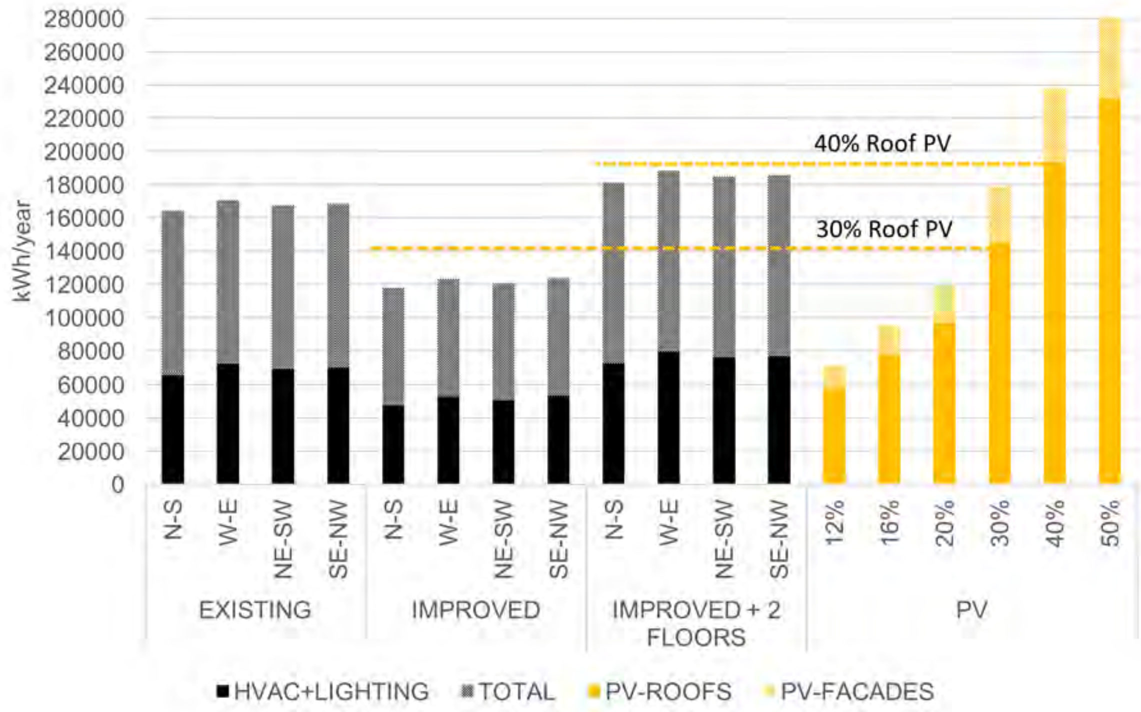


Figure 1. Electricity consumption by building in various orientations compared to roof and facade PV installation for electricity generation.

Densification Programs in Israel

The land is the most precious natural resource in Israel. Despite the importance of protecting the open spaces and natural areas, the situation shows a constant reduction of these areas. According to "Sustainability Plan for Israel 2030" (Ministry of Environmental Protection and Jerusalem Institute for Israel Studies, 2012) a recommended strategy is concentrated dispersion and revitalization of existing city centres.

To minimize damage to open spaces, in the early 2000s an urban renewal plan was developed. Within the framework of the plan, the government of Israel proposed two main tracks for the promotion of municipal urbanization processes (Ministry of Construction and Housing, 1999):

1. Urban Renewal (increased building rights)
2. Urban Redesign (clearance and construction)

The aim of both tracks is better land utilization within built-up areas, the creation of a new housing inventory in cities and their improvement by upgrading existing buildings and infrastructure. In the context of the “Urban Renewal” track, the committee promotes the intensification of built-up areas without demolition activities and maximal use of existing infrastructures. The “Urban Redesign” route requires fully re-planning of an existing area with significant plot densification and related infrastructure renewal. The case study complex in our work is facing an approved “Urban Redesign” densification program. Plot density will increase by more than 200% compared to the existing condition. The densification plan and general design layout was already approved by District Committee in 2015.

Urban Densification Alternatives

In this paper, we introduce two additional alternatives with increased urban density to the previously discussed plot case study (Figure 2):

0. Existing – Current plot condition (Kolodiy and Capeluto 2016).
1. Approved – plot design as approved by District Committee.
2. Proposed – redesign of approved building's volumes to maximize electricity production potential by minimizing mutual shading, and maximizing usable roof area.

0. Existing 1. Approved 2. Proposed

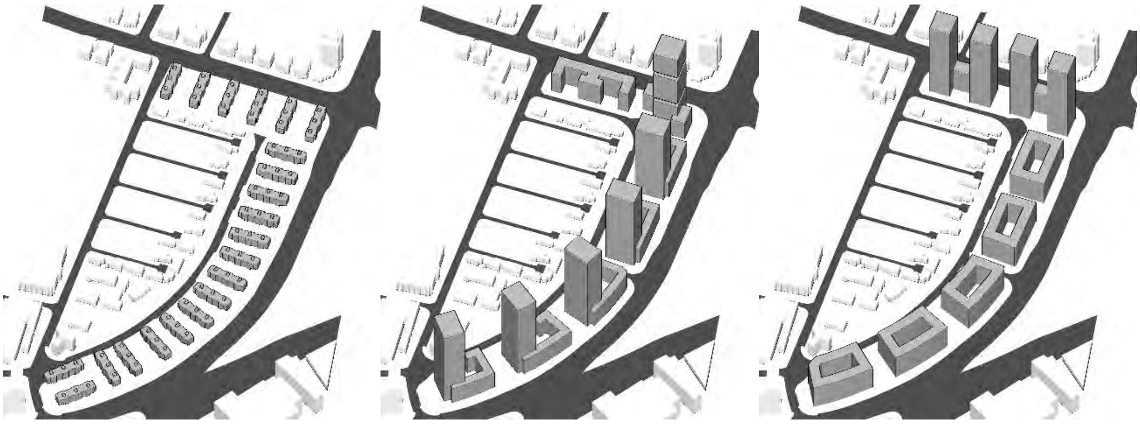
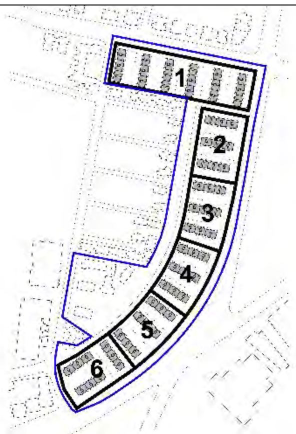


Figure 2. Plot Design Alternatives schemes compared one to another.

The existing plot condition density is 10.7 units to 1 dunam. It does not match to the minimal density requirements by in force National Building Plan 35 (Ministry of Interior, 2010), which is 12 units to 1 dunam. The newly approved plot design will increase plot density by about 3 times. With both densification design alternatives, (1) approved and (2) proposed, both with improved insulation, we achieve equal plot density, namely 32.4 housing units to 1 dunam (Table 1).

Table 1. Comparison of housing units amount by plot and design alternatives.

Case Study Plot with New Site Division	Plot Number	Units Amount by Design Alternatives		
		Existing	Approved	Proposed
	Density (unit/dunam)	10.7	32.4	32.4
	1	132	391	680
	2	66	201	143
	3	66	201	143
	4	66	201	143
	5	66	201	143
	6	66	201	144
	Total	462	1396	1396

The aim of this study is to check how near in the way to zero energy can we get within plot borders with future plot density conditions? Can we ameliorate the approved plot design in terms of energy consumption and electricity generation within plot borders?

The approved option presented in this paper shows the design alternative by Yashar Architects Ltd. This alternative contains three building block types (Figure 3). The first one is an eight-story long type building (Type 1), the second one is a 30-floor tower with eight floor base on the lower levels (Type 2). These two types appear one time on plot number one within the case study area. The third block (Type 3) is six story building connected to the 25-floor tower and appears 5 times at plots number 2, 3, 4, 5 and 6. In this case the potential surfaces for PV panels' installation are reduced and unclear because of mutual shading.

The proposed option was designed to increase on plot solar yield potential. The plot designed to enable maximum roof surfaces fully exposed to solar radiation and maximise on-site electricity production. As the previous alternative, it contains three building block types. Two blocks of eight story buildings connected to two 20 floor towers above (Type 1, 2). These blocks have minor geometry differences due to actual plot borders. They appear once at the northern plot (number one) to maximize towers south façade exposure to solar radiation and to prevent any shading on other on plot buildings' roofs. Third, a European block (Type 3), appears five times on plots 2, 3, 4, 5 and 6. This block is nine story building with flat roof fully exposed to sun radiation (Figure 3).

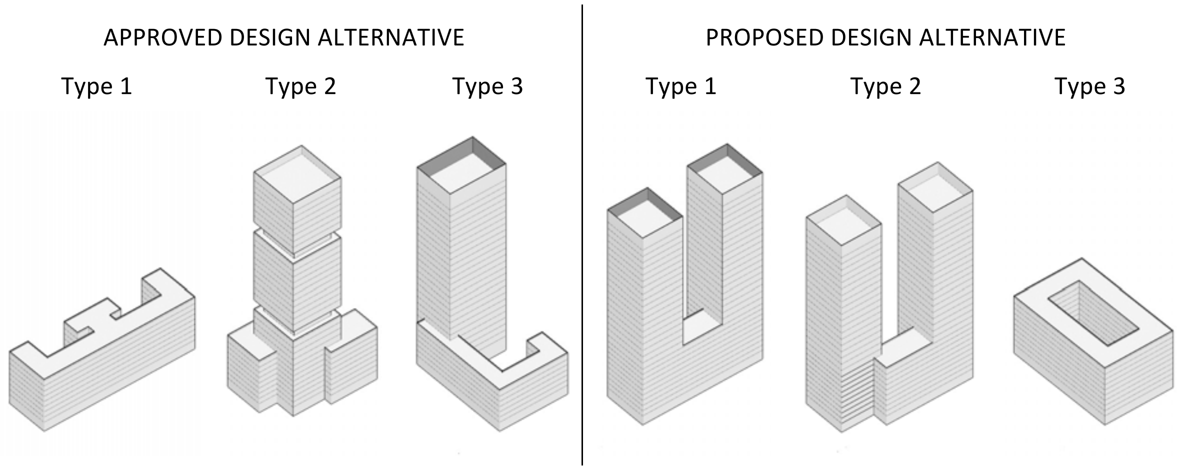


Figure 3. Building block types of "Approved" and "Proposed" design alternatives.

In both design alternatives, the ground floor of all building types was considered as non-residential, public floor, as approved in the original plan. As well, both alternatives aim to maximise on site density conditions but do not consider on plot or neighbour building's solar rights. Design within solar envelope borders to consider solar right of all neighbours will significanty reduce on plot density.

Energy Consumption

Following the previous study method (Kolodiy and Capeluto 2016), the first step for estimating energy plot consumption was to detect buildings' types and identify housing units' types. According to the approved design, there are two main types of housing units in every building block type. Type A apartment, is a unit with single openings' orientation. Its depth does not exceed ten meters to provide basic daylight access and ventilation. Type B apartments are corner units, and have openings in two different directions. These two base types, A and B, has many subtypes that vary in unit's area, orientation and number of external walls.

The second step, was to perform energy simulations (Kolodiy and Capeluto 2016) using Energy UI based on Energy Plus simulation engine. The energy model was built as a tower type building to assess maximum number of unit types with minimum calculation times. Units' windows in energy model were set according to the Israeli Energy Rating of Buildings Standard (ST 5282-1, 2011), namely 15% of the floor area. Although, in Energy Rating Standard openings' sizes varies according to facade orientation, the maximum allowed size was applied to each unit according to Israeli residential design habits.

According to the results, south oriented A and B units have better energy performance results than north oriented. West and east oriented units have slightly higher energy consumption compared to north and south, while the west oriented units are the worst.

The study shows that in case of tower type building with a central core and housing units around it facing all directions, orientation has no significant effect on its overall energy consumption. However other building types, as a long type or European type, are better to be north-south oriented. These buildings' energy consumption decrease as much as more housing units are south or north oriented. According to the study, the total energy consumption of both, approved and proposed, alternatives is similar. The proposed design option, has slightly higher results because of type 3 building elongated block's east-west orientation.

Electricity generation

A PV system was chosen for electricity on site production. To identify suitable surfaces for PV panels' installation, solar radiation simulations were conducted with DIVA for RHINO. Simulations were applied on both plot design alternatives.

As a result, we detected the total annual solar radiation amount which reaches each building's surface. For calibration purposes, the simulations outcome was compared to the solar radiation data from the Design Guide for PV Systems in Israel`s Cities (Faiman et al, 2000). According to solar simulations results, radiation values on surfaces were similar to data that appears in PV Guide (Table 2). For final calculations, the guide radiation data was used as highest radiation value.

Table 2: Solar radiation on various surfaces in Tel Aviv
(Faiman et al., 2000).

Plane orientation	Plane Tilt	Solar Radiation (kWh/m²/year)	DC Output (kWh/1kWp/year)	Solar Radiation Simulation Result (DIVA) (kWh/m²/year)
	Horizontal	1862	1422	from 1840 to 1873
South	Vertical	1244	828	
South-East	Vertical	1337	889.9	from 1345 to 1289
West	Vertical	1125	778.1	
South-West	Vertical	1244	860.7	from 1205 to 1166
East	Vertical	1036	805.3	

In addition to fully exposed areas, shaded surfaces were checked. If obtained radiation was lower than the basic, fully exposed value, annual electricity production was calculated relatively to the PV Guide data. If annual solar radiation on surface was less than 1000 kWh/m²/year, similar to minimum value presented at table 2, it was not considered as suitable for PV array installation. It was found that about two thirds of roof surfaces of the Approved alternative receive up to 1600 kWh/m² annual radiation and are then suitable for PV array installation. Additionally, upper levels of south oriented facades exceed 1000 kWh/m²/year and can be therefore be considered for energy generation. However, west oriented facades, were not considered due to low radiation results on then resulting from plot's slight rotation to the north.

Typically, tower's roofs are occupied by technical equipment and PV arrays cannot be installed. Therefore, tower type buildings' roofs weren't considered as surfaces for potential energy production. In addition, the three lower floors of each building weren't considered for PV potential. Lower, public floor usually has glazing façade with no opaque surfaces for PV installation, and partial or constant shading can be caused by urban infrastructure as trees, street lights, traffic signs and others.

Results and Conclusions

According to the comparison between the case study plot energy consumption and electricity production within buildings' borders, near zero energy goal can be achieved for certain density and technological conditions (Figure 4).

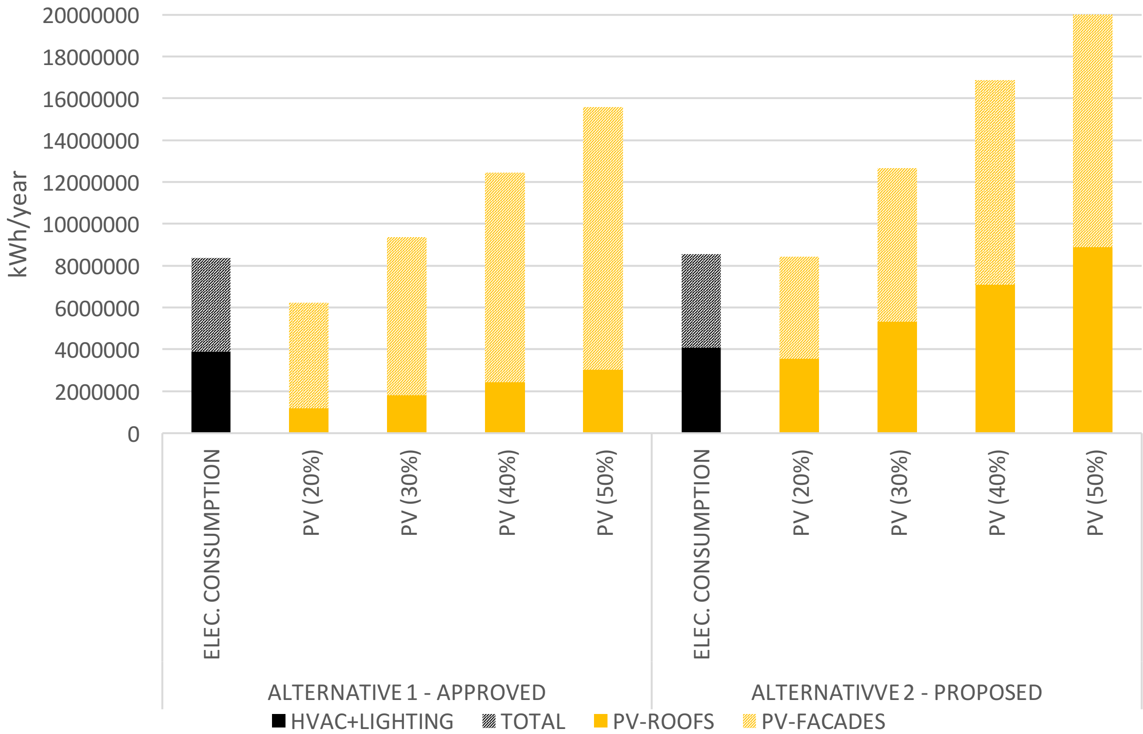


Figure 4. Case study plot various design alternatives' electricity consumption compared to energy production by PV roof and façade installation with various efficiencies.

In case of the approved alternative, big vertical PV array systems can be implemented due to the large façade areas of tower type buildings. However, roof surfaces are small and mostly shaded, therefore PV production potential cannot be maximized. In this alternative roof electricity generation is about 20% of total on plot production.

On the other hand, the proposed alternative offers larger, fully exposed roof areas for maximum electricity production. In this case, PV roof array with 20% efficiency, can provide more than 80% of the total plot energy used for HVAC and lighting, and depends less on facades. Facades surfaces area is slightly smaller than in first alternative so as electricity production from PV array implemented on them. The proposed design enables to produce more energy, although its energy consumption is slightly higher than in case of the approved alternative.

As noted before, horizontal roof PV installations have less impact on building appearance. Roof systems are easier to install and provide future maintenance. If PV array on façades is implemented, further aesthetical design issues should be considered:

- Façade surfaces covered by PV requires flat, fully exposed facades design. Shading elements or balconies will decrease on facade energy production potential.
- PV façade array implementation, limits the cladding material variety. In addition, PV cladding increases expenses of the finishing material and its maintenance. Future developments in PV field may provide more colors, shapes and textures for more various façade designs.

The study shows that zero energy or near zero energy goals is difficult to accomplish if urban and building design relies mainly on façade installation as in the proposed option. It is important to implement solar oriented design on urban level as much as on smaller building scale in order to reduce energy consumption and maximize energy on-site production. In the future, with increased efficiency of photo-voltaic panels and proper design at urban and building scales, zero energy should be reachable goal for presented density developments.

Further studies should examine the limitations of zero energy design for higher urban densities with increased mutual shading, and for lower solar radiation in different countries around the world.

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Heated living: Residents' evaluation of heat(ing) in low carbon architecture

Sonja Oliveira[1*], Bill Gething [1], Elena Marco[1], Michelle Agha-Hossein[2] and Tassos Kougionis[2]

[1] Department of Architecture and the Built Environment, University of the West of England, Bristol, UK
[2] BSRIA Sustainable Construction Group, BSRIA Limited, Old Bracknell Lane West, Bracknell, UK

Abstract: Low carbon homes are often designed to accommodate advanced heating control technologies. These technologies are expected to contribute to better performing buildings and a comfortable indoor environment. Recent research focusing on the role of the occupants' interaction with heating controls has identified a number of areas that can influence the in-situ performance of the heating systems installed. Complex interfaces, non user friendly programming instructions, poor functionality as well as badly located controls can all lead to poorly performing homes and reduced indoor comfort. Whilst increasing efforts have been made to better understand residents' engagement with heating control systems in a range of housing types, there is a lack of evidence on the ways residents manage and adapt comfort in a low carbon homes taking into account the wider context of a development. This paper draws on residents' experiences across 40 dwellings in a recently completed innovative low carbon residential development in the UK. The study seeks to extend existing knowledge on ways residents manage comfort in their homes with a specific focus on heating practices in low carbon developments. Implications of the research are twofold. First, the study contributes to a better understanding of the emerging roles of motivations, expectations and mitigation patterns in living in domestic low carbon environments. Second, there are implications for design professions to take account of the potential implications specific physical 'prompts' such as windows, balconies and wallspace can have on the ways comfort is 'controlled' within a home. There are also implications for national and international energy policies on low carbon developments specifically in relation to heating.

Keywords: controls, energy, heating practices, housing, low carbon architecture

Introduction

Almost half of the energy consumed in the UK is generated by space heating, most of which is from the domestic sector (Chaudry et al 2015). A series of policy initiatives aimed at decarbonising heat highlight either the need for new low carbon homes (HM Government 2011), new heating systems (CCC 2016) as well as better management and control of existing systems and technologies (DBEIS 2016a). Moreover, a diverse range of energy systems' scenario modelling have also been undertaken analysing pathways towards 80% reduction of emissions by 2050 (Chaudry et al 2015). UK policy largely focuses on technical solutions via energy efficiency measures and renewable energy. For example, the energy white paper (DTI 2007) includes an analysis of all UK sectors and the likely carbon emission reduction to be achieved in each sector by 2020. The list of measures mentioned is largely based on energy efficiency improvements, more efficient generation and generation from renewable and nuclear sources. Often the context of the technology is viewed in isolation of type of home, location and climatic conditions within which a home is situated as well as age, condition and occupancy patterns within a home. Also, the potential contribution from behavioural changes is not mentioned in the document, neither are policies that encourage such behavioural shifts.

Adding to a growing number of policy initiatives, industry reports and academic discussions have been examining the underlying implications of residents' approaches to new low carbon homes, technologies and systems. Several scholars focus on explaining why and how above average consumption of energy and heat specifically can occur. In most cases this is found to be down to residents' 'lack of control capability' and poor understanding of manuals and handover packs (Gill et al 2010) as well as badly located controls with complex interfaces, often inaccessible with non user friendly programing (Stevenson et al 2013). Devine-Wright et al (2014) analyse how older adults engage with new heating technologies post installation finding how their practices become influenced by pre-existing meanings associated with the 'making of a home'. Whilst some scholars have focused on interaction with particular technologies such as controls; others emphasise the need to study heating as constituted within 'meanings of culture, spatialities, technologies and bodies' (Fennel 2011).

Despite the growing diversity and growing quantity of academic discussion dedicated to analysing heating in traditional and low carbon homes, few studies examine how residents perceive heat in their indoor environments beyond 'interacting with technologies'; and the ways they manage and adapt to new ways of heating within the spatial, cultural and technological contexts of their home, street and wider community. The present paper builds on research that views heating as intertwined with cultural, sensory and spatial factors by examining residents approaches to 'heat' in a recently built low carbon development in South West England. In particular, the paper is interested in what and how residents manage their 'heated' environment and respond to both delight and difficulties they may encounter when moving into a low carbon home both within the confines of their home but also at the scale of the development.

Heating controls, manuals, systems and residents

How well a home performs has been suggested by a growing body of research to be dependant amongst many issues, on how users approach their indoor domestic environment particularly in relation to controls. Controls and their usability have been a topic of an increasing number of discussions particularly in low energy homes where there may be a number of advanced control technologies installed.

Problems with controls have been described in terms of mainly technical issues including the growing complexity of confusing interfaces, inconvenient location in homes (Stevenson et al 2013), increasing number and range related to different aspects of comfort, poor functionality (DECC 2014, DBEIS 2016b) and issues with slow or no feedback (Peffer et al 2011). In addition, studies have begun to highlight some of the social and cultural difficulties in communication between users and designers, poor handover practices, lack of knowledge amongst both users, site managers, contractors and designers (Andersen et al 2016; Bell et al 2016) and at times lack of interest to improve current practice across the built environment (Leaman 2012). Also, a number of studies have suggested particular research methods used such as questionnaires tend to overestimate users' understanding of controls thereby at times ensuring socially acceptable responses (Monahan and Gemmell 2011; Shipworth 2000)

In low carbon developments in particular users tend not to make adjustments to controls due to complex technology or unfamiliarity leading to uncomfortable conditions in indoor environment (Bell et al 2010). In addition, often low carbon developments include separate controls for different services complicating management of homes further (Monahan and Gemell 2010). For some scholars key difficulties lie in poor handover practices and often very complex manuals that are difficult to understand (Pett and Guertle 2004). Stevenson and Rial (2008) suggest difficulties lie in poor knowledge and understanding can be found across the design team. Discussing the post occupancy survey carried out for the Sigma house, Stevenson and Rial (2008) observe how Housing developer's representatives were not always familiar with the more complex controls, referring the user to the induction guide book.

Heating as constituted through culture, specialities, technologies and bodies

Whilst an established area of research focuses on improving usability of controls, recent work by Hellwig (2015) suggests greater attention needs to be placed on exploring perceptions of the environment 'being controlled'. The environment can include broader social and cultural issues as argued by Fennell (2011) whose study of heating enables a greater understanding of the relation between heating and culture, spatialities, technologies, and bodies. In her ethnographic study conducted in Chicago public housing, she finds that heating is intertwined with class and race dynamics, politics and the bureaucratic regulation of a common sensory regime. Using a similar approach, Cupples et al (2007) discuss heating as constituted within national identities and notions of masculinities. Embedded widespread and common practices of using log burners and open fires to heat homes, despite leading to significant air pollution in Christchurch, were found to be deeply tied to notions of 'bearing the cold' and cultural identities linked to the colonial past.

Hards (2013) discusses ways that domestic energy practices reflect status and stigma, noting how the adoption of wood-burning stoves – defined as 'positional goods' – in the United States in the early 19th century was a form of conspicuous consumption. The argument presented by Hards suggests that energy consumption is both a way of conferring status, through conspicuous consumption, or stigma through a person's inability to conform to societal norms with regard to energy consumption. The mobilisation of different forms of capital, including social, economic, cultural and symbolic is important here in both establishing one's status position, but also in avoiding stigma (Hards 2013). Devine-Wright et al (2010) suggest that perceptions of cosiness in a home occupied by older adults led to installation of wood burning stoves and fake fireplaces despite the installation of highly efficient low carbon thermal technologies.

A deeper understanding of how cultural factors mediate sensory experiences and practices is believed by some to be crucial for the development of sustainability-driven policies, especially in light of common discourses on climate change and energy security (Harrison and Popke, 2011; Hitchings and Day, 2011). However, the scarcity of approaches on the experience and attitude towards heat within and outside a 'low carbon home' as well as beyond the systems and technologies that enable it is striking. Whilst the studies discussed in this section of the paper discuss housing and heating broadly, they enable an important understanding of how heating and comfort are positioned within a wider set of relations between status, stigma (Hards 2013), national identity and notions of masculinities (Cupples et al 2007) as well as concepts of cosiness and glow (Devine-Wright et al 2010).

Research setting and methods

The research setting is based on a recently built low carbon development in South West England consisting of over 185 homes ranging from one-bed flats to five-bed houses. The homes were originally designed to be zero carbon in accordance with Level 6 of the Code for Sustainable Homes (CSH).

Research methods- data collection and analysis

Data collection commenced in June 2016 and was completed in Jan 2017 with analysis and literature reviews overlapping. Interview and focus groups sessions involved a total of 48 participants. Initially 5 focus group sessions were held with groups ranging from 6-12 participants. During the focus group sessions, questions probed issues surrounding residents' expectations of the development when moving in, reasons for choosing to live in the development as well as circumstances that led to the decision to purchase a home in the development. In addition, questions were concerned with approaches to controlling heat in their indoor environment, daily routines, meanings, as well as changes to expectations and experiences in their home and wider development. Following the focus group sessions, in-depth semi-structured interviews in 10 homes with 12 participants of diverse ages and backgrounds were held to explore particular aspects that emerged in the focus group discussions. Houses varied from flats, coach houses, 2 bed, 3bed and 5 bed houses located throughout the development. In addition, two homes were shared ownership with the housing association, whereas others were fully privately owned. These were complemented by interviews with housing association managers, site managers and designers where relevant. The research was mindful of ethical issues and was conducted on an entirely confidential, anonymous and consensual basis.

Analysis of the focus group and interview data was informed by thematic analysis (Braun & Clarke, 2006). Data were initially coded into 3 main categories (Background and reasons for moving to development; Experience of living in the development; Views on the indoor thermal environment and how it is adjusted) with more than 30 subcategories; and the main themes presented here stem from a subsequent round of analysis probing issues of heat, control and mitigation strategies as they emerged across the dataset, from which the findings laid out below were drawn. Emergent thematic categories included: ***Justifying investment in home***, ***Managing discomfort*** and ***Learning what a home needs***. Care is taken in the following discussion to bring out differences between the home contexts (where these are significant), alongside identifying areas of commonality. As reiterated above, the authors are not seeking to generalize from this limited set of cases. Rather the thematic analysis is used to identify some of the key considerations relevant to thermal experience in diverse home settings in a low carbon development, whilst recognizing that these will be manifest differently in other settings.

Findings

The findings are discussed across three key 'Activity' themes: ***Justifying investment in home***; ***Managing discomfort*** and ***Learning what the home needs*** (see Figure 1). In all themes discussions centre around physical and social 'prompts' (within the home as well as outside in the wider development) as well as symbolic notions centering around types of control engagement.

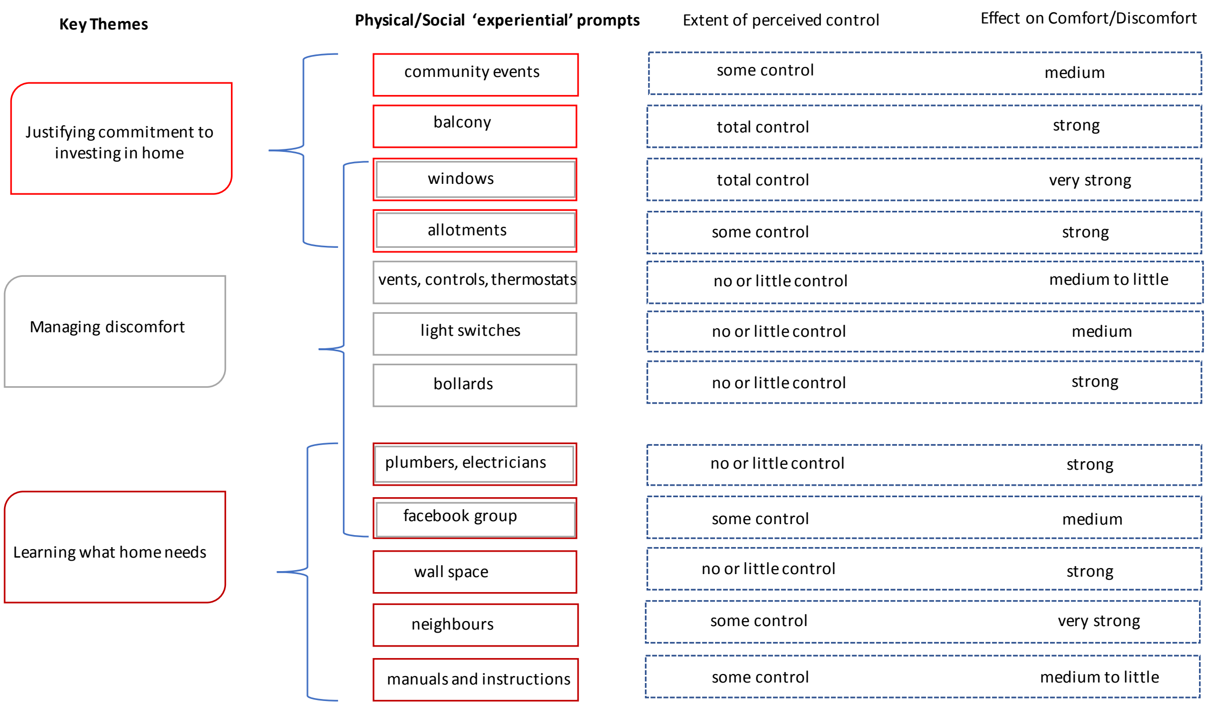

Figure 1 Overview of key themes

Justifying investment in home

In most cases residents interviewed found the development by chance; in magazines, portals or local adverts whether moving from elsewhere in the country or elsewhere within the city. In many cases residents chose to live in the development in order to be save money; seeing the key attraction of the homes in promoted low running costs. In some cases, residents were drawn to the advertised 'sense of community' and in some cases the eco features promoted in the sales leaflets such as 'rainwater harvesting', 'solar panels' or 'recycling'. In most cases residents were moving from conventional homes located within a street and had never lived in an estate type development or a new build home. In very few cases did the sustainable ethos of the development play a major part in residents deciding to purchase a home on the site.

> "We moved to the development because we needed to downsize and needed to be frugal with money…obviously its reduced bills here…"(Linda and Richard)

For most of the residents, the move was about a transition to a new stage of life such as retirement, being divorced, 'children moving out' and left on own or 'children staying at home' and needing more space. Whilst most residents did not choose to live in the development because of its low carbon credentials, many were drawn to the idea of a 'created community'. Residents, having described how they moved to the development would often begin to discuss features of their home or development that were unexpected or disappointing. 'Buying into' a community and finding that most residents were not 'eco' or did not share the promoted ethos of the development was often reflected upon.

Dalia moved into the development having lived in the city most of her life and being familiar with the area. Though she wasn't planning to buy she did note how she 'stumbled across' the show home and was offered to buy on the condition 'she sold hers by 5pm that night'. She chose her particular home because it had a kitchen window on the corner, allotments nearby and a balcony 'so the dog could watch people come and go'. However, she was to find a type of community (her home was close to what she described as the social housing bit) she did not expect and a home which she felt she 'did not have what it needed' in terms of 'knowing what to do and how to use it'.

> "I hadn't quite realised the impact of living here as there is quite a lot of drama; sometimes its like living in the middle of Eastenders with the bailiffs, police, paramedics, fire engines. You can get them all in one night, all outside my own house…" (Dalia)

Despite being disappointed Dalia goes on to justify the fact the home is invested in already (emotionally as well as financially) by reflecting upon the 'community as being lovely and a 'microcosm of the country' as well as observing how 'a home is somewhere you have to love' reminding us of the fact her house has 'lots of light and that extra kitchen window; a corner window'.

Managing discomfort

When discussing how they found their indoor environment in terms of comfort, most residents noted long periods of adjustment, 'not having what the home needed' and not knowing were things were or how they worked. The home was described by one resident as needing a particular set of skills and knowledge (that she perceived was lacking).

> "Initially they (the developers) just wanted your deposit down…bear in mind I'm blonde and I'm artistic…and to live here you need to have mathematical brain…and preferably a partner"…(Jasmine)

In most instances residents describe their home as too hot, reflecting upon the vents 'as being everywhere', the balcony 'as a social corner and chance to breathe'. When prompted to describe how they 'cool their home' in most instances 'windows are left wide open' and 'vents are not touched'. One resident noted how 'heating controls had a life of their own' and controlling them meant "tak(ing) a glass of sherry, cross(ing) my fingers and press(ing) the buttons". For some, the sense of helplessness in managing the indoor home environment was conflated with a sense of social isolation and being 'on your own'.

In some instances residents (particularly those seeking an eco community) viewed themselves 'knowing something others don't'. Yvonne and her husband live in a 2 bed house, having already lived in a similar 'eco development up north'. The described their knowledge and interest in eco living as being familiar and long established. They also describe how they learn of 'others who don't seem to realise the MVHR needs maintaining' or the solar panels need cleaning'. They also discuss how a lot of time was spent 're-specifying the house' so light switches were zoned as built.

Discomfort of the indoor environment was often reflected upon through other disappointing features within the home such as a 'lack of wall space being occupied by doors and technology', or 'light switches in strange places such as behind the door' as well as outside the home such as bollards 'that no one warned us about'. Bollards were viewed as being installed without resident consultation (post completion) and were viewed as obstructing the ways residents could use the 'front of the house' such as opening of front doors for 'cross ventilation' as they might 'encourage cars to get closer to the front door'.

Learning what the home needs

Whilst discussing adjusting to their new home environment, residents often described a long process of learning over periods of 2-4 years as an unexpected issue. In many instances, welcome packs and instructions were described as 'being wrong', 'referring to a different type of control' and not giving enough of an insight into the 'type of lifestyle this needed'

> "I was a little bit of a guinea pig….so they showed me a building and asked me what questions I had, but they didn't handover much, apart from a generalistic pack, so I had to find out myself. They also said some things that were utter rubbish; they said don't ever touch the ventilation system which is utter rubbish as you obviously have to change it to summer mode…"(Dalia)

For most residents learning involved reliance on others whether a next-door neighbour, an electrician *'who visited and fixed the controls'* or wider community social media such as a Facebook page or manual. In many discussions, a manual produced by one of the residents on use of controls and maintenance of systems would be brought up or the Facebook page where residents could post their issues with the development or their home. Most residents, however, did not seek to question difficulties encountered or complain to the developer or housing association in the first instance. Instead residents noted how they had used controls before and 'it should not be that difficult'. In some instances, residents did not alter the programming since moving in finding themselves often opening widows throughout the day and night as their home was too hot.

Active learning meant seeking advice from plumbers and electrician, who often 'simply could not help'; 'or did not know'. In two instances, residents bought an alternative thermostat 'because another resident has done it'.

Discussion and conclusion

Extending Shove's argument (Shove et al 2009), findings in this paper similarly suggest a need to analyse the dynamics of domestic energy use as intertwined with and through different aspects of everyday life. The study reported in this paper, however, highlights the possibility of understanding how adaptation, use of physical and social prompts lead to particular outcomes. How can placement, use and spatial relations of physical/social prompts such as community events, windows and light switches motivate behavioural learning or adaptation? It has been established for some time in anthropology that the built environment can hold repositories for social meaning, physical bodily orientations and identities (Fennell 2011). In addition, research in the built environment has observed detailed relationships between comfort and clothing (Cupples et a 2007), furnishings and openings (Raja et al 2001; Nicol 2001). This study extends this work by highlighting how the use of prompts (both physical and social) within and outside the home obstruct or enable particular approaches to heat and heating in low carbon homes.

Within UK policy, the concept of a zero or low carbon house has been (re)defined several times. Currently, three elements are required for a house to be classified as low carbon: 1) the energy demand must be reduced to comply with the Fabric Energy Efficiency Standard (FEES); 2) any remaining carbon emissions must be below the Carbon Compliance Level; and 3) any remaining carbon emissions must be offset through investment in Allowable Solutions projects such as offsite renewable energy sources (ZCH, 2014). Missing are broader implications of physical placements of home components- vents, switches, windows, balconies as well as positioning of outdoor elements such as bollards and allotments. Instead too often the focus is on the technological components of heating systems such as valves, controls, thermostats or boiler inaccessible technology and users lack of preparedness or understanding. Further research is need to better understand the ways physical and social components of a home environment (both inside and outside) help shape how heat is approached, controlled or ignored. There are implications in his paper on designers of both homes as well as the environment that surrounds them (the gardens, landscaping and parking) and the potential importance they play in the way decisions on comfort and heating in particular are made by residents.

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Design to Thrive

New insight on passive ice making and seasonal storage of the Iranian Yakhchal and their potential for contemporary applications

Hareth Pochee[1], John Gunstone[1], Oliver Wilton[2]

[1] Max Fordham LLP, London, UK, h.pochee@maxfordham.com
[2] The Bartlett School of Architecture, UCL, London, UK, o.wilton@ucl.ac.uk

Abstract: The Yakhchals of Iran are a type of ancient structure and system used to produce, harvest and store ice for cooling uses later in the year. In this paper, the authors present an explanation of how Yakhchals are understood to have operated and then go on to present analyses of aspects of the ice making and storage processes. A transient 1D heat transfer model is used to predict of how much ice could be made over the course of a year. A second transient heat transfer simulation is used to predict the amount of ice that could be retained (not melt) over the storage season. Finally, the potential for a modern day application of passive ice making and storage for space cooling in an ultra-low energy office is explored.

Keywords: Yakhchal, ice, passive, cooling, simulation

Introduction

The Yakhchals of Iran are relatively well-known (Hosseini & Namazian, 2012) and their method of making and storing 'ice in the desert' via passive means has influenced the current generation of passive and low energy designers. The use of ice from Yakhchals for cooling drinks and food was reported to be common in Iran by John Fryer in the late seventeenth century (Beazley, 1977) and some Yakhchals were reportedly still in active use as recently as the 1960s (Jorgensen, 2010). Yakhchals are found across Iran in areas where the climate enables the freezing of ice on site in winter, or where ice and snow could be brought from nearby mountainous areas (Hosseini & Namazian, 2012).

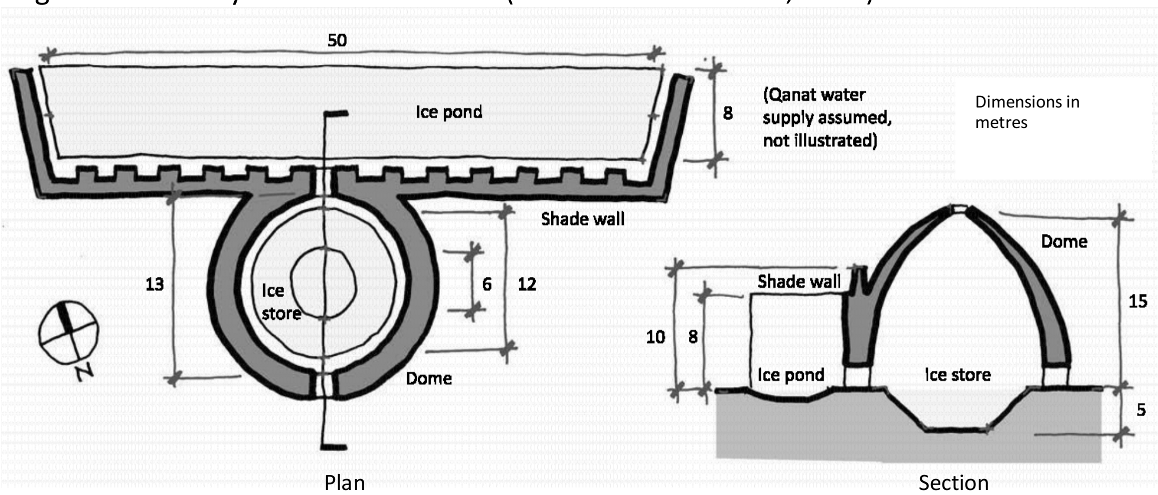

Figure 1. Meybod Yakhchal. (Adapted from Ghobadian, 2001 as referenced in Hossieni and Namazian, 2012)

Figure 1 illustrates a particular large, dome type Yakhchal in Meybod, in the province of Yazd on the Iranian plateau, which is reported to be around 400 years old and has recently been partially restored. The complex includes an ice production pond, which is protected from the low winter sun by a shade wall, and a store where ice is kept for use in the warmer months. The shade wall and dome structures are typically made of mud bricks or adobe, sometimes made using soil extracted from the local ice pond and store excavations (Jorgensen, 2010).

In this paper we present the results of analyses of several building physics aspects of the large dome type Yakhchal and ice pond structures within Yazd climatic conditions. There are several aims; to understand and simulate the heat transfers used to form ice; to make predictions of the amount of ice that could be produced; to understand and simulate the physics of the ice storage process; to make predictions of the amount of ice that could be retained (not melt) from winter to summer; to understand how the architectural designs of the structures contributed to these effects; and to investigate if passive ice making and storage could be made use of in a modern architectural context.

Anecdotal evidence from historical accounts regarding quantities of ice production vary, CJ Wills describes the ice production process in Shriaz in 1891; "A few inches of still clear water is collected in the pond, by morning it is frozen; at night the water is again admitted, and another inch or two of ice made. When three to six inches thick, the ice is broken and collected for storage in a deep well on the spot : and so day by day the process goes on during the short winter until the storehouses are full" (Wills, 1891).

Other physics based analyses have been carried out; Jorgensen presents an ice yield estimate from the Abarqu ice pond in Yazd district of 100cm/yr. However, having reviewed this work we feel that the work over estimates both the ice formation rate at a given temperature and the extent that Yazd's climate resides at sub-zero temperatures leading to a gross over prediction of ice yield. Zare et al derived an expression for the thickness of pond ice produced based on climatic conditions (Zare & Davoodmoosavian, 2015). The same paper presents an analysis of dome shaped stores concluding that dome shaped stores absorb less solar radiation than flat roofed equivalents.

Climate Data

The climate of Yazd is very dry, with hot summers and cool winters. The average annual precipitation is less than 100mm/yr. A TMY hourly climate data set (IRN_Yazd.408210_ITMY) is available for Yazd (Energy_Plus_Weather_Data, 2005). Figure 2 illustrates the hourly dry bulb temperature for this set showing that summer temperatures occasionally exceed 40°C and winter temperatures occasionally drop below -5°C. TMY data sets use a cut and paste approach from many years of data to synthesize a "typical" year's climate data. The Yazd TMY year uses data from 1961 to 2004.

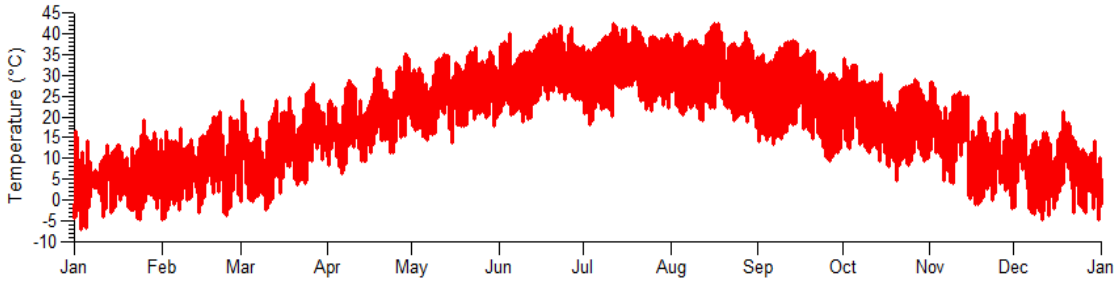

Figure 2. hourly dry bulb temperature from the Yazd TMY (Typical Meteorological Year).

Ice Production Modelling

A 1D numerical model (the "MF Pond Ice Model") was created to simulate the heat transfer processes in the Meybod ice pond.

Figure 3 illustrates the pertinent model parameters. The model uses the Yazd TMY hourly climate data set for the external variables. The convection, sky radiation, and evaporation models implement the methods proposed by Tang and Etzion (Tang & Etzion, 2005) and Hamza (Hamza, 2007).

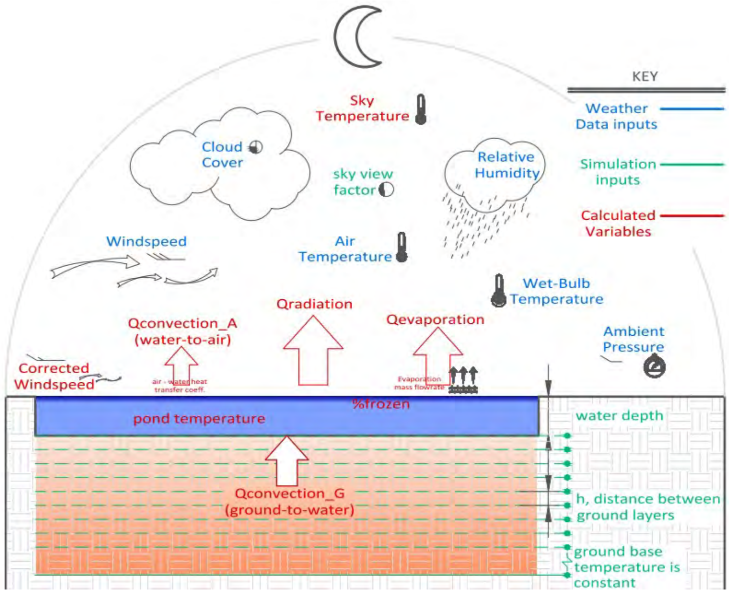

Figure 3. Ice making model features and parameters. "Q" is used to represent heat transfer

The ground below was modelled as 5m thick layer with a base temperature fixed at 19°C (the annual average air temperature). The ground thermal conductivity used was $0.3Wm^{-1}K^{-1}$, a value for dry clay soil 5% m.c. proposed for Yazd by (Dehghani-sanij & Sayigh, 2016). The ground initial temperature was modelled with a spatial distribution defined by the method provided by Kasuda (Kusuda & Achenbach, 1965) which results in a temperature of about 4°C at the pond base and 19°C at 5m depth.

The pond itself was modelled as a homogeneous medium 100mm thick with the thermal properties of either liquid water, or ice depending on its temperature. The freezing (or melting) phase change was modelled by keeping track of the amount of energy in a theoretical "latent store" Using this procedure, when the pond reaches 0°C and receives further cooling the temperature of the water is fixed to remain at 0°C and energy is subtracted from the latent energy store, which when fully depleted signifies a complete phase transition from water to ice for the whole pond. For intermediate states, the thickness of ice layer is assumed to be equal to the total pond depth multiplied by the % that the latent store is empty.

The pond area was assumed to be $416m^2$, estimated from drawings of Meybod (Figure 1). It was assumed that each evening in winter, at 9pm the pond is filled with 100mm of water with temperature equal to the external air temperature at that time. The ground temperatures below the surface are calculated from the results of the previous day. After 11 hours of simulation any ice >3mm thickness predicted to have formed is "harvested" and the process repeats again for the next day. The assumed view factor from the pond to the sky was 0.7. The simulation was run for 3 years using a 5 minute time step. The results presented are for the final year of the run.

MF Pond Ice Model Results

Figure 4 illustrates the predicted daily ice yield. The maximum predicted ice yield is 12mm/day. The total predicted yield is $49m^3$/yr, equivalent to a total thickness of 120mm and a latent coolth store of 4.3MWh. Figure 5 shows the predicted average hourly heat transfers for the coldest week of the winter (in January). Radiation heat loss to the sky is found to be the dominant cooling mechanism, but the modelling shows that evaporation is also significant, much more so that convection to the external air. Convection heat gains from the relatively warm ground are also small in comparison to the losses from radiation and evaporation.

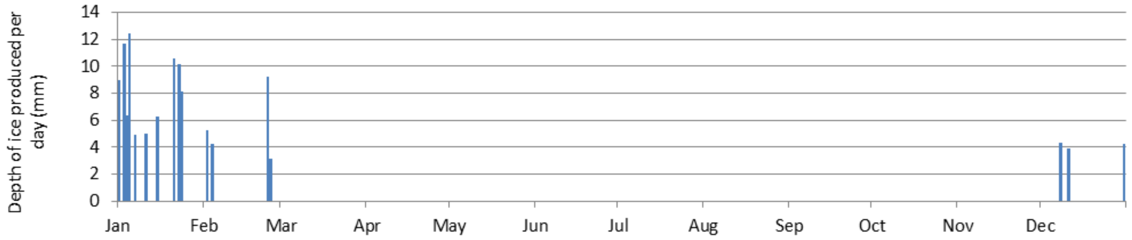

Figure 4. MF Pond Ice Model results of daily ice production in the Meybod ice pond.

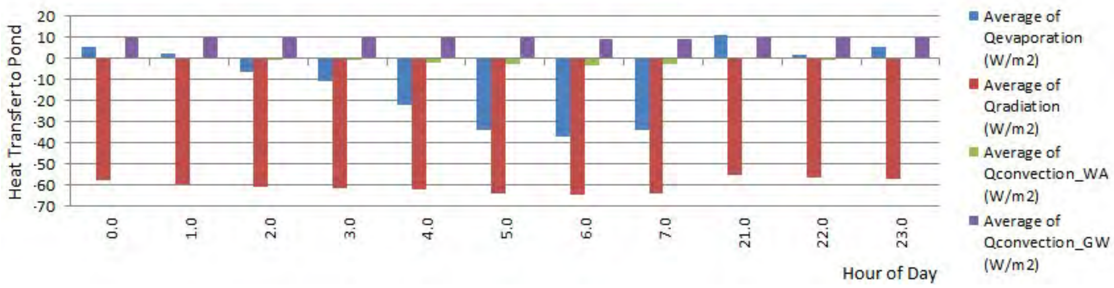

Figure 5. Model results of heat transfers in the Meybod ice pond. The values are the average value at the stated time for all the days of the coldest week.

Ashton Ice Formation Model

The Ashton Ice Model is an empirical model proposed for thin layers of ice on open fresh water bodies (Ashton, 1989). It depends only on the duration of cold air temperatures, expressed as freezing degree days (FDD) and empirical constants. The Yazd TMY data set has 20 FDD, for which the Ashton Ice Model predicts 70mm of ice.

Ice Storage Modelling

Heat transfers within a typical dome Yakhchal have been modelled using a 3D dynamic thermal simulation with the Virtual Environment software by IES (IES VE, 2015) using the hourly Yazd TMY climate data. The model geometry and pertinent model parameters are illustrated in Figure 6. For the walls and the ground the model implements a layered 1D transient conduction model, allowing temperature penetration depth and time lag effects to be represented.

(Hosseini & Namazian, 2012) report that straw, or thatch insulation was placed around and within the ice packs and also on the outside of the dome. They also state that the layer of straw insulation over the icepack top surface could have been 1 to 2m thick. The model material properties are given in Table 1. The initial run used 0.5m of thatch insulation in all locations.

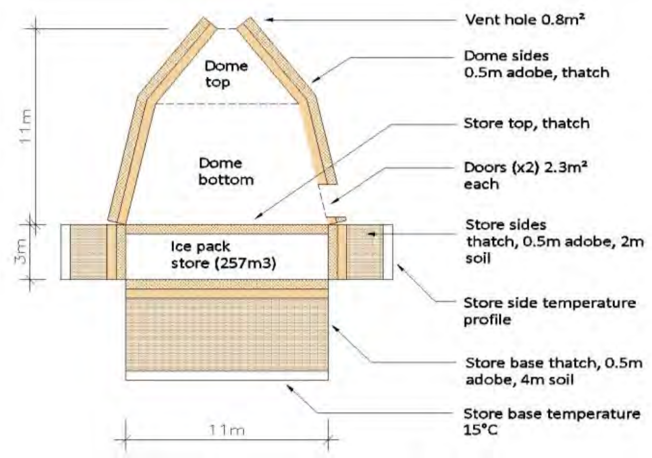

Figure 6. Ice storage model parameters

Table 1: Ice storage model material properties

Material	Thermal Conductivity (W/mK)	Density (kg/m^3)	Specific Heat Capacity (J/kgK)
Adobe	0.6	1700	900
Thatch	0.1	250	1800
Soil	0.3	1000	1900

The store side and base temperatures were estimated using the Kasuda equation for ground temperature with an estimated correction for the long term cooling effect of the presence of the ice store. The base temperature was kept fixed at 15°C. The store side temperature profile was set to vary according to the season in the following way J,F,M: 8°C; A,M,J: 16°C; J,A,S: 30°C; O,N,D: 16°C. The model was started with an initial temperature of 10°C. The IES model uses the climate data to simulate the effects of solar radiation, longwave sky radiation and convection to the dome external surfaces.

The ice pack was modelled as a zone with a (variable as needed) cooling load applied to keep the temperature at 0°C. The store volume was assumed to be full of ice. The model calculates the conduction heat gains into the store from the dome and surrounding ground. The amount of ice melted is calculated from the total seasonal heat gains (cooling load) into the ice pack store.

Ice Storage Modelling Results

Figure 7 shows the predicted internal dome (bottom) temperature for a scenario called Store_10 which has the doors closed, the top vent unshaded and open for ventilation and the thatch 0.5m thick. The annual total heat gain (cooling load) of the ice store is predicted to be 4.6MWhrs which equates to 52m^3 of ice melt or 20% of the total store volume.

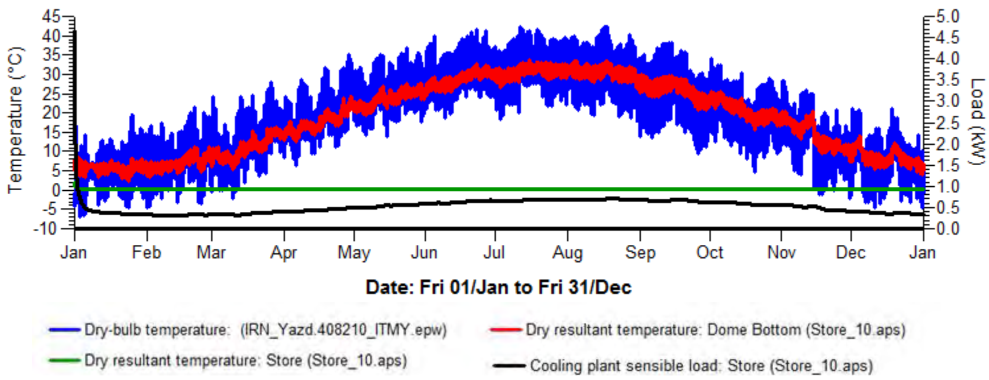

Figure 7: Store_10 scenario ice storage modelling results.

The distribution of annual heat gains into the store for Store_10 is found to be 15% through the floor, 15% through the sides and 60% through the top surface to the dome; which shows that the dome's ability to keep cool could significantly affect how much ice melts. However, it should be noted that this work assumes soil with a very low thermal conductivity, which keeps the heat gains from the ground to a low fraction of the total.

Several other scenarios have been simulated to investigate how the system could perform in both the past and the present. It was found that adding shading to the top vent so that the dome solar gain is zero has negligible effect on the store heat gains. However, employing a ventilation manager (in either human or machine form) to open the doors whenever the external temperature is lower than the internal dome temperature reduces the melt losses by 1%. Removing the thatch on the dome exterior causes melt losses to increase by 1%. Most benefit can be gained by investing in store insulation; if 1m of thatch is used at the base, sides and top of the store the melt losses are reduced to 13%. If 0.5m thick of polyurethane foam (with k=0.02W/mK) is used the melt losses are predicted to be 6%.

Contemporary Application: An Ultra-Low Energy Office

A concept ultra-low energy office has been modelled using IES VE with the Yazd TMY climate data. The concept design is one that minimises the cooling load. The model geometry is illustrated in Figure 8. Other key features of the model were: 10m^2/person occupancy from 8am to 6pm. High thermal mass floor, walls and ceiling. Windows sized to provide 2% daylight factor with solar control glazing and external shading that automatically deploys to block 80% of direct sun. Lighting and computer heat gains of 4W/m^2 and 5W/m^2 during occupied hours; an additional heat gain of 2W/m2 all the time and ventilation at 8l/s/p of fresh air when occupied. The design and model also included additional free cooling ventilation providing 20ac/h of external air whenever beneficial. A cooling system is included that attempts to cool to 26deg C but is limited to 8W/m^2 (1kW) peak output.

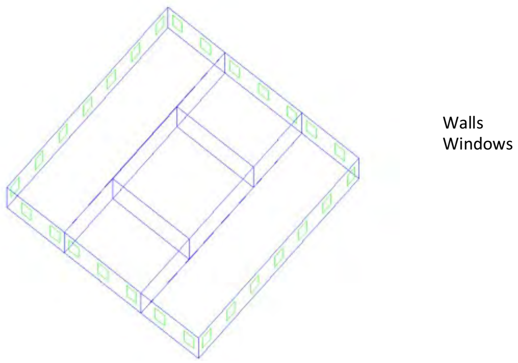

Figure 8: Ultra low energy office model. Single storey with 400m^2 floor and roof areas.

Ultra-Low Energy Office Model Results

The results of the modelling for the west facing side of the building are illustrated in Figure 9. The peak cooling output is limited and results the internal temperatures shown. The model predicts that a typical hot day has an internal temperature of about 33°C when the external temperature is 40°C. The total annual cooling demand is 3.5MWhrs.

An assesement of thermal comfort was made using the adaptive thermal comfort method descibed by (Mohammad & Shea, 2013) which, for the Yazd climate data defines the following monthly comfort temperatures; May 28°C, Jun 30°C, Jul 31°C, Aug 30°C, Sep 29°C. The results showed that comfort temperarures were exceeded in 20% of occupied hours.

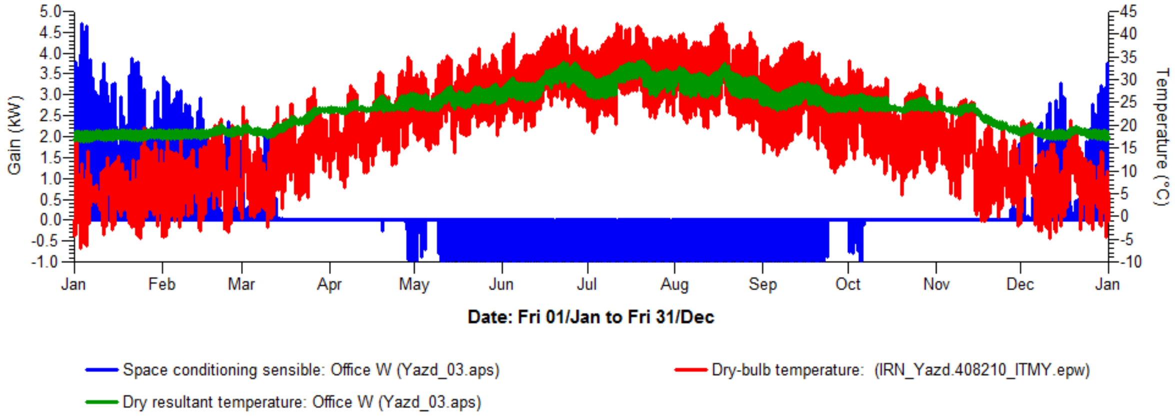

Figure 9: Ultra low energy office model results

Discussion, Insights and Conclusions

Ice Production

A 1D transient heat transfer MF Pond Ice Model was developed. When used with Yazd TMY climate data the model predicts the amount of ice that could be made in a sun shaded pond over one winter to be 120mm total thickness. This was in general agreement with the Ashton Thin Ice Model which predicts 70mm for the same climate data. A lower yield from the Ashton method is expected since the Ashton empirical constants were measured for lakes subjected to solar radiation. Whereas, due to their operation at night and shading structures, the Yahkchal ice ponds receive little or no solar radiation.

As expected, sky radiation was found to the dominant cooling mechanism but evaporation was also found to be significant. For the coldest week in the data set The MF Model predicts typical night time average pond heat losses of 60W/m^2 for sky radiation, 20W/m^2 for evaporation, 1W/m^2 for convection to air and 8W/m^2 heat gain from the ground. The MF Model assumes that evaporation effects are always active (even when ice has formed), in this respect it probably over predicts the ice formation rate. However, including evaporation always is a reasonable approximation if the water is gradually applied in layers on top of an existing ice sheet. This is mode of operation is therefore recommended to maximise yield and there are historical reports in the literature that suggest this was indeed done.

The simulation work also showed that harvesting ice each morning was more beneficial that leaving it out. This was because, even with the shading wall in place the amount of diffuse solar radiation heat received was greater than additional available daytime cooling.

The estimated size of the Meybod ice store is 200m^3. The predicted winter ice yield from the 416m^2 production pond was 49m^3, 25% of the size of the store. There are several possible explanations for the predicted low fill fraction including one or more of the following; the pond may be genuinely undersized compared to the store; the physics model may be deficient; the assumptions for model inputs may have been flawed; the TMY climate data may not provide a good representation of ice making conditions compared to reality (either now or in the past).

Ice Storage

A numerical model was used with the Yazd TMY climate data to simulate the heat transfers within a large dome type Yakhchal similar to the one at Meybod. The model used a 1D approximation of heat transfers from the below ground store into the surrounding soil. The model assumed a 257m^3 underground store packed full of ice surrounded by a layer of insulation. The modelling results predicted annual melt losses of 20% for 0.5m thatch insulation, 13% for 1m thatch and 6% for 0.5m of modern polyurethane foam insulation.

Potential Contemporary Application

A concept single storey 400m^2 ultra-low energy office in Yazd was modelled using a dynamic thermal simulation. The model included very high standards of passive design along with a maximum active cooling output of 8W/m^2 resulting in an annual cooling load of 3.5MWh (9kWhr/m^2/yr). The Ice Production analysis predicted an annual ice yield of 120mm/yr. Therefore, siting a pond over the whole 400m^2 office roof could produce 48m^3 of ice per year which could be stored in an insulated pit under the building. Allowing for 10% melt losses, the avaialble latent coolth from the ice store would be 3.7MWh, i.e. slighly more than the annual space cooling demand. However, it was found that internal condictions within the office were not always comfortable; comfort temperatures were exceeded in 20% of occupied hours. Convieniently ignoring cost or any other feasibility issues, the work has shown that using passive ice making and seasonal storage alone can, in principal meet a significnt fraction, but not all of the space cooling demand in a contemporary single storey ultra-low energy office. The cooling capacity of the system could be enhanced by also making use of summer roof pond cooling such as the type descibed in (Tang & Etzion, 2005) which, when combined with the seasonal ice harvesting might be possible to meet 100% of the building cooling load.

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Bringing Pupils into Building Energy Performance: School Design, Construction and Operation

Francesco Pomponi[1], Liliana Medina Campos[2], Alice Moncaster[3] and Sean Smith[1]

[1] Edinburgh Napier University, Institute for Sustainable Construction, EH10 5DT Edinburgh UK f.pomponi@napier.ac.uk;
[2] Universidad Colegio Mayor de Cundinamarca, Bogotá, Colombia
[3] The Open University, School of Engineering & Innovation, Milton Keynes, UK

Abstract: Colegio Rochester is school in Colombia with a strong vision for sustainability. This vision permeates the new school building which was the first school in Latin America to be awarded a LEED Gold certification. This article uses Colegio Rochester as a case study to understand how the individual roles and interactions between stakeholders, including pupils, shaped (and still shape) the energy performance of the building. Primary qualitative and quantitative data have been collected including interviews with the LEED consultants and multiple users, and a detailed analysis of the energy performance figures. The data was used to map users and the key connections between them, developing an understanding of the inputs that different users have had throughout construction and use of the building, and the drivers and impediments that have characterised the project. The energy performance in use was also compared against the modelled energy consumption predicted at design stage, showing a strong alignment with the real figures, in fact, lower than those predicted. The result of this case study is a detailed insight into how a project was delivered with a negative performance gap, with recommendations as to how this approach can be replicated across the Global South and the rest of the planet.

Keywords: school building, building users, performance gap, LEED, holistic sustainable building design

Introduction and background

The influence that a healthy, positive and comfortable built environment in schools has on students achievement and behaviour is not new (e.g. Earthman and Lemasters, 1996). However, in a world where global warming and climate change threaten the global environment with potentially disastrous catastrophes, such optimal learning environment must be achieved in an energy efficient manner.

Energy efficiency in schools is generally investigated from the perspective of a specific measure, be it a low-energy technology, an energy reduction measure or a passive design strategy. For instance, Becker et al. (2007) investigated design solutions for schools in Israel that would maintain good levels of thermal comfort and indoor environmental quality whilst being at the same time energy efficient, what they called the EE-TC-IAQ dilemma.

Theodosiou and Ordoumpozanis (2008) addressed the same 'dilemma' for nurseries and elementary school buildings in a cold climatic zone of Greece. Their results indicate that main causes for energy inefficiency are to be found in the building envelope, the lack of apt legislative measures, and an improper control of lighting and heating systems – among others (Theodosiou and Ordoumpozanis, 2008). Dimoudi and Kostarela (2009) monitored the energy consumption and assessed the energy conservation potential of school buildings also in a cold climatic zone in Greece. Their monitoring and simulations revealed that in that context improved thermal insulation has the greatest benefit on the reduction of energy consumption, followed by increased wall thickness and better airtightness (Dimoudi and Kostarela, 2009).

Sekki et al. (2017) investigated the effect of energy measures on the values of energy efficiency indicators for school buildings in Finland. In the cases they studied, the most savings in energy consumption can be achieved through investments in technical measures or by operating an automated building management system based on the actual occupancy of the school (Sekki et al., 2017). Research on energy efficiency in schools has evolved greatly given the continuous increase in computational power and refined software tools. One such example, is the work of Zhang et al. (2017) that employed a simulation-optimisation approach based on multi-objective genetic algorithm to improve thermal and daylight performance of school building in China. The authors adopted a parametric approach related to spatial configurations and found that the best design could lead to a 28% energy reduction (Zhang et al., 2017). Schools have also been analysed from a life cycle perspective, in order to understand how minimise material use and waste generation. For example, Pons and Wadel (2011) looked at prefabricated timber, steel and concrete structures. Depending on the technology used, they found that CO2 emissions could be reduced by 50% or waste generated during the school building's life cycle cut by 40% (Pons and Wadel, 2011).

Not only do such interventions on a school building foster a healthy and comfortable educational environment, they also have a further, beneficial and often untapped potential: that to educate and promote sustainability amongst future citizens (Hertzberger, 2008). Whilst this has been already noted and pointed out in the literature on energy efficient schools (e.g. Theodosiou and Ordoumpozanis, 2008) there currently is a lack of research on the benefit and impact of a more holistic approach to school design, with a focus on the roles that different users and stakeholders have. This is therefore the focus of this paper, which will use a K-12 school in Latin America as a case study to reflect on the role of a school building as a living textbook and understand how the individual roles and interactions between different users, including pupils, shaped (and still shape) the energy performance of the building.

Colegio Rochester

Colegio Rochester was established in 1959 as a K-12 private educational institution teaching English as a second language in Bogotá, Colombia. In 2000 the School Board set out to develop a wholly new educational facility with open areas, a good infrastructure for the arts, a swimming pool to promote a wider range of sports, and innovative classrooms to facilitate learning and teaching. The new facility also had to embed sustainability at its core and promote environmentally friendly strategies throughout design, construction and use (Colegio Rochester, 2014). The very ambitious idea was to use the new school site as a living text book, and even more, to make it a tool to transform society in Colombia (Medina Campos, 2015). Many successful initiatives have been organised, that involved not just the school's users such as teachers and pupils but the wider society as a whole, through families of the pupils and the members of the neighbourhood where the new school site sits. This holistic approach to sustainability, in addition to excellent design and environmental management has led to Colegio Rochester receiving the LEED Gold Certification in January 2014, being the first school in the whole Latin America to achieve such accomplishment (Colegio Rochester, 2016). Colegio Rochester has been recognised by national and international organizations such as the Kimberly Clark Foundation Ekco-Awards recognition in 2013 for Exceptional Places to Work, BIBO-WWF in 2014 and as “Academy – Best Environmental Practices” and “Green Project Challenge - 2014”. In 2016 EU press included Colegio Rochester as one of the 50 world’s most innovative schools (El Tiempo, 2016). Since 2012 Rochester School is leading “Green Apple Day” in Colombia and “Our Choice”, an integrative K- 12 networking initiative based on sustainability educational strategies for schools since 2014. In 2016, the WWF awarded Rochester for the protection of the environment (WWF, 2017). Given the remarkable achievements across the whole sustainability spectrum, Rochester made therefore an ideal case study to understand the implicit and explicit aspects that led to such a successful project.

Data collection

Primary data were collected by the authors, starting in May 2016 and continuing through to 2017. Data collected were both qualitative and quantitative. The former consisted in exploratory interviews with LEED consultants as well as semi-structured interviews with school stakeholders. The latter resulted in modelled and measured energy consumption to assess whether and to what extent the low energy technologies employed in the school design had had the expected positive impact. The interviews were realised with:

- Two senior members of the school management
- Two environmental managers
- Two teachers
- Two technicians, and
- Two students

Energy figures were obtained from the energy simulations performed in 2013 as a requirement for the LEED certification. This consisted in carrying out a computer based energy use simulation of two buildings, the baseline building design according to Appendix G of ANSI/ASHRAE/IESNA 90.1-2007 (ASHRAE, 2007) Energy Standard for Buildings Except Low-Rise Residential Buildings (Performance Rating Method) and the proposed building design that incorporates technologies and alternatives (SES, 2013). Ex-post measured energy figures were obtained from the independent energy audit that monitored real energy consumption from November 2012 to January 2017 (SES, 2016, Colegio Rochester, 2017).

The construction materials were evaluated with Design Builder to validate the thermal behaviour, and finishing materials with high surface albedo were chosen. In terms of ventilation, a mixed mode with fresh air intake operates throughout the building and all classrooms are equipped with temperature and CO_2 sensors. The water centre instead fully relies on a natural ventilation strategy with relative humidity of 65% and temperature in the range of 24-30°C. The Colegio also benefit from a range of renewable systems, including 92 PV panels for a total of 24446 kWh/year, solar thermals for hot water and pool hearing, and daylighting system (i.e. Solatube).

Results and discussion

The first result that was produced from the analysis of the interviews has been a flowchart mapping all stakeholders that have influenced and participated in the project across the different stages (pre-executive design stages have not been considered, e.g. planning permissions). This is shown in Table 1.

Table 1 - Stakeholders across different stages of the project

SUPERVISING ALL STAGES

- School Board (General Manager)
- Sustainability and LEED Consultants
- Commissioning Authority
- School Sustainability Director
- Architectural Firm specialised in schools

DESIGN PHASE STAGE 1	DESIGN PHASE STAGE 2 and CONSTRUCTION PHASE STAGE 1	CONSTRUCTION PHASE STAGE 2	OPERATION and FACILITY MANAGEMENT
▪ Architect ▪ Design builder modeller ▪ Energy modelling consultant ▪ Wastewater treatment consultant ▪ Ventilation system design engineer ▪ Lighting design engineer ▪ Acoustic design engineer ▪ Structural engineer ▪ Environmental consultant ▪ Renewable energy consultant	▪ Renewable energy design consultant and contractor ▪ Hydraulic consultant and contractor ▪ Landscape design consultant and contractor ▪ Construction firm	▪ Ventilation system contractor ▪ Electrical and sensors contractor ▪ Wastewater treatment system contractor ▪ Flooring contractor ▪ Ceiling contractor ▪ Windows contractor ▪ Solar tubes contractor ▪ Lighting contractor	▪ School sustainability director ▪ Environmental manger ▪ Sustainability consultant ▪ School facility manager ▪ Teachers ▪ Pupils ▪ Technicians ▪ The wider community

Table 1 reveals some interesting aspects. Firstly, the boxes and arrows show those key actors that have supervised the project across all stages as well as being directly involved in some of them. These are: the environmental and sustainability consultants who played different roles throughout the project, also acting as LEED consultant, the school sustainability director who is actively involved in managing and overviewing the school buildings' operation as well as in supervising the facility management, and the commissioning authority currently acting as facility manager.

Once the building has been completed, it was immediately used as a living text book to engage pupils in all grades and let them have a real feel for what sustainability is about in practice. For example, as a student reported in the interview, visits to the school's wastewater treatment plan (which is the most critical element) helped them understand the purpose of having solely biodegradable soaps and washing up liquids. Additionally, and more importantly, the pupils understood the effects (both positive and negative) that virtuous or vicious behaviours could have on the whole system. Both students in the interview showed an admirable awareness of their roles as sustainability champions, and this was in fact a general feeling during the fieldwork at the school; all pupils at all grades were strongly engaged with the sustainability theme and very aware on how they could promote sustainability and contribute to a better environment.

The building has also been used as one of the main elements of the sustainability curriculum which is taught, with the due differences, at all grades. The school has introduced a sustainability area coordinator as a new role to manage and overview the curriculum and its continuous refinement and evolution. In all interviews it emerged that the school's vision and its sustainability curriculum were so forward-thinking that they actually started driving cultural change. However, as some interviewees have revealed, this also became problematic when pupils – especially those at lower grades – received a different message at home from their parents. Rather than seeing this as a setback, the school decided to broaden even more its outreach and activities for pupils and their families have grown in number and in scope. This solved to some extent the dual message that children were being exposed to, by "educating pupils as well as their families" as one of the interviewees put it.

A different difficulty was experienced with students at higher grades, which already had their own views and perception about sustainability. In these cases, it was not just the sustainability curriculum that drove change but, equally – if not more –importantly, the commitment of the School Board, the School Sustainability Director and all the teachers. Through a holistic approach and the coherent message, all students successfully and positively engaged with the new buildings, the advanced and low-energy technologies used, and the rationale for doing so. Similar to this was the experience of technicians and other support staff working at Colegio Rochester. For them, the new school site has represented a paradigm change since they "were not educated thinking about sustainability", as reported by one of the technicians interviewed. However, over time, the technicians have become sustainability champions too, they enjoy their daily jobs, and feel part of a bigger system which truly cares about humans and the environment. During the interviews it also emerged the formative roles of the technicians, which have frequent and effective interactions with students in order to show them how systems work, how their use of technologies can be improved or rectified in order to reach together a very ambitious goal.

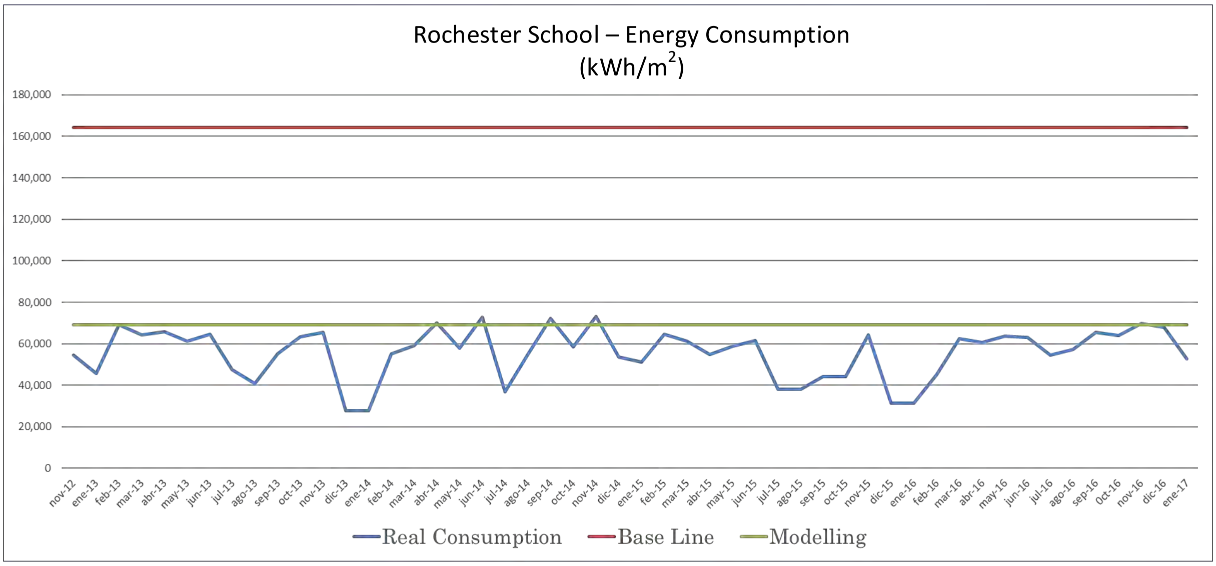

Figure 1 - Modelled vs. measured energy consumption [2012-2017] - Courtesy of Rochester Facility Manager

In addition to an evident positive contribution to promoting social sustainability through the key role education plays, all these activities have had a remarkable impact on the energy consumption of the new school buildings. Figure 1 shows the base line, modelled, and measured energy consumptions from November 2012 through to January 2017. Real figures on energy consumption were collected from the CODENSA (Colombian Energy Supplier) energy bills for all months covered in the chart.

It can be seen that when the measured energy is compared against the modelled energy consumption predicted at design stage, it shows a strong alignment with the real figures, in fact, lower than those predicted. This is a noteworthy achievement, particularly at these times where a big performance gap seems to be the norm in buildings' projects (Forman et al., 2017). Colegio Rochester has fully realised that building users play a crucial, yet "poorly understood and often overlooked role in the built environment" (Janda, 2011 p.15), and has therefore put them right at the heart of the building energy consumption. Not only Colegio Rochester performed very well against the modelled energy figures, but it also performed brilliantly overall compared to schools' energy consumption. This is can be seen in Figure 2, which shows the Energy Intensity Index based on Energy Star.

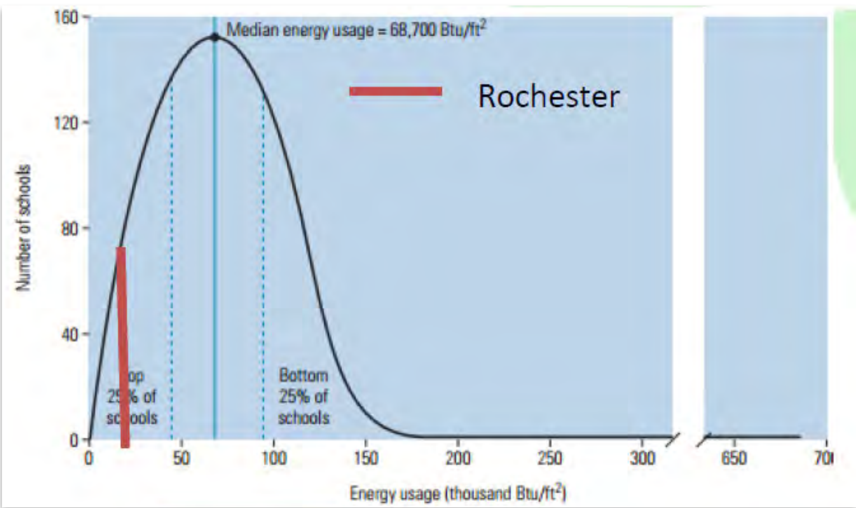

Figure 2 - Colegio Rochester's energy performance compared to other schools - source: SES (2016)

Colegio Rochester is located in the upper bound of the schools with lowest energy consumption. The energy audit conducted in 2016 other than assessing how the building had performed in the previous four years was also an opportunity to re-assess the modelled energy figures and evaluate further energy reduction and optimisation measures. Despite a strong agreement between modelled and measured energy (Figure 1), the energy audit has revealed that individual energy loads could be better modelled (e.g. there had been an overestimation of the ventilation loads and an underestimation of the lighting loads). The energy modelling has been adjusted in light of real figures and therefore the predicted energy consumption in the future will be even more accurate.

The energy audit has also recommended further interventions for energy reduction, which have then been evaluated by the School Board and Facility Managers to evaluate their implementation. Two such examples are lowering the operational temperature for the aquatic centre pools and the elimination of lighting parasitic loads. The former was rejected because pools temperature is set according to national and international norms for comfortable swimming and therefore the energy saving intervention would affect the pupils. The latter instead could be implemented, after checking with the Security Manager that adjusting lighting timers would not pose any increased security risk. Even in these two cases it can be seen that pupils are always placed at the heart of building-related decisions, after all the school exists for and because of them. It shall not surprise that when they are given so much consideration, their behaviour in return is fully committed to achieving a low-energy, sustainable building.

Conclusions

Colombia, like other countries in Latin America, faces great challenges related to the inclusion of sustainability principles and to social and economic development (UNEP, 2014). Education can play a key role in many different aspects, and can certainly help promote paradigm shifts amongst new generations that will be the leaders of tomorrow. This is true across the whole sustainability spectrum, which includes sustainable buildings. This paper has shown how a school building can become a living text-book and give pupils a very concrete experience on how sustainability in the built environment is designed, practically implemented, and managed.

Colegio Rochester is not only an award-winning school but a social phenomenon that has successfully engaged with its many stakeholders across all stages of the building process through to operation and management of the new building site. Pupils have been recognised as key users, and are continuously put at the heart of the school's activities. They are highly engaged with the sustainability theme and have become passionate sustainability champions. As a result, the building has performed better than predicted over the past five years, with measured energy figures lower than those modelled at the design stage. The approach followed, the design utilised, and the technologies implemented are all highly replicable and can be adopted and adapted to different contexts. As such Colegio Rochester could be an excellent model on how sustainability in school can be replicated and achieved across the Global South and the rest of the planet.

Acknowledgements

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Design to Thrive

Productive facade systems for energy and food harvesting: A prototype optimisation framework

Abel Tablada[1], Vesna Kosoric[1], Siu Kit Lau[1], Chao Yuan[1] and Stephen Lau[1]

[1] Department of Architecture, School of Design and Environment, National University of Singapore, Singapore.

Abstract: Building facades in tropical low-latitude regions usually receive ample sunlight; hence, the integration of solar and farming systems may greatly contribute to the productive role of buildings. This paper discusses the development and optimisation of modular productive solar facade (PSF) prototypes suitable for residential buildings involving the implementation of Building Integrated Photovoltaics (BIPV) and Building Integrated Agriculture (BIA) systems. Design alternatives are created by means of an integrated design process (IDP); whereas the VIKOR multiple criteria decision analysis (MCDA) method is applied for a holistic assessment and for the selection of the optimal design alternatives in view of the conflicting criterion categories: architectural quality, production performance and financial performance. Owing to the complexity of PSF integration, in addition to the final food and energy yield, the design optimization considers the impact that arrangements, geometrical forms and types of facade elements may have on the indoor daylight conditions, shading and thermal performance, and wind permeability. At this stage, preliminary results regarding the optimal BIPV on north and south facades, as well as vertical farming arrangements are available. Two optimal facade prototypes for each orientation will be installed and tested at the Tropical Technologies Laboratory (T^2 Lab), at the National University of Singapore campus.

Keywords: BIPV, vertical farming, residential buildings, carbon neutrality, tropical architecture

Introduction

The transition to carbon-neutral societies requires a gradual paradigm shift in lifestyle and building design. Buildings and urban landscapes should become a primary source of energy, food and water, instead of being merely the receivers. As cities extend and their life intensifies due to the rapid growth of urban population in Asia and in tropical regions, a high degree of self-sufficiency in terms of energy, food, and water supply should be guaranteed in order to achieve such transition, while also adapting to climate change and mitigating its effects. Tropical low-latitude regions have ample sunlight; therefore, building facades could greatly contribute to the productive role of buildings by implementing Building Integrated Photovoltaic (BIPV) and Building Integrated Agriculture (BIA) systems.

Several studies have been conducted on the integration of Photovoltaic (PV) panels on building facades in Singapore. Wittkopf et al. (2008) report on the BIPV design development, final designs specifications, and tender assessments of the Zero Energy Building at Building Construction Authority (BCA) Academy in Singapore that includes BIPV as shading devices. However, no details are provided regarding their performance. Saber et al. (2014) studied the PV performance and energy yield predictions of the BCA Academy in Singapore. Through data-collection and simulations, Saber et al. (2014) concluded that a 30° slope is the most effective angle for PVs in Singapore. Mandalaki et al. (2014) compared different shading systems that incorporate BIPV in terms of visual comfort and energy yield. They concluded that the brise-soleil and the single-inclined overhang perform well in terms of energy production and visual comfort. However, their study refers to Mediterranean climate were sunray angles are on average lower than in tropical latitudes. Luther and Reindl (2014) made an estimation of the potential PV area to be installed on Singapore's building facades in order to achieve energy yield equivalent to that provided by 4 km^2 of roof-top PV panels facing the sun at an optimum angle.

Most studies on BIA focus on the rooftop as the potential farming area (Lim and Kishnani, 2010). Other studies on vertical farming concentrate on indoor farming with air conditioning systems and electrical light being used (Despommier, 2013). The application of farming systems on building facades from the construction point of view was reported by Suparwoko and Taufani (2017). However, only Tablada and Zhao (2016) thus far investigated the integration of both solar and farming systems on building facades on an urban scale.

In order to achieve a successful architectural integration, the complexity and dynamics of PV systems design require a holistic multi-disciplinary approach (Hestnes, 1999; Kosorić et al., 2011; Munari Probst, Roecker, 2012) as well as the application of integrated design process (IDP). Solar facade prototype enables fine-tuning of different functions and it balances production performance with architectural qualities (Zoltan et al., 2016). The development of a productive solar facade (PSF) prototype involving BIPV and BIA systems that accomplish multi-dimensional functionalities is an iterative process that includes multiple and often conflicting quantitative and qualitative parameters. The optimal solution should meet specific architectural and techno-economic requirements while at the same time complying with a number of different constraints (safety, accessibility issues, etc.). Therefore, this paper focuses on the development of a multiple criteria decision analysis (MCDA) framework which will be used for the design optimisation of the PSF systems to be installed at the Tropical Technologies Laboratory (T^2 Lab) at the National University of Singapore (NUS) campus. Two modular facade prototypes per orientation suitable for residential buildings will be developed: (1) facade wall and (2) facade with balcony (or corridor).

The VIKOR method (Opricović and Tzeng, 2004; Opricović and Tzeng, 2007) is increasingly applied in areas related to sustainability and renewable energy (Mardani et al., 2016). Regarding the integration of active solar systems into buildings, the VIKOR method can be successfully applied to enable comparisons of otherwise incommensurable or conflicting requirements and to provide greater modelling flexibility according to the preferences of the decision-maker (Kosorić et al., 2011; Krstić at al., 2012). In this paper, MCDA VIKOR method is applied in order to provide a comprehensive evaluation and selection of the optimal design alternatives. In addition to food and energy yield, the optimisation method considers the impact of the facade design on the building thermal and visual performance, functionality, and costs. The research is based on the hypothesis that the performance of building facades should exceed the traditional indoor–outdoor boundary functions and climate regulation by also providing a portion of energy and food that residential buildings require. The benefits that each BIPV and vertical farming system can provide are two-fold: on one hand, they enable the production of electricity and food;

on the other hand, as passive devices, they reduce solar gains as well as improve indoor visual and thermal comfort.

Optimisation framework

Figure 1 shows the overall framework of the MCDA applied in this study. The first step was to define the potential BIPV facade components, vertical farming and fenestration or openings. For each system a series of preliminary simulations was conducted and the technology was selected based on the available reference literature. Thereafter, the decision goals were identified considering the potential integration of PSF in residential buildings. The result of considerations is a simple rectangular form of SPF with a relatively neutral appearance. Key parameters such as: production outputs, installation and maintenance costs, user comfort, accessibility, and aesthetics, also have to be balanced. Design alternatives are then generated to be applied on two facades types: (1) facade wall and (2) facade with balcony. Both facade systems are analysed separately for four orientations: north, south, east and west orientation.

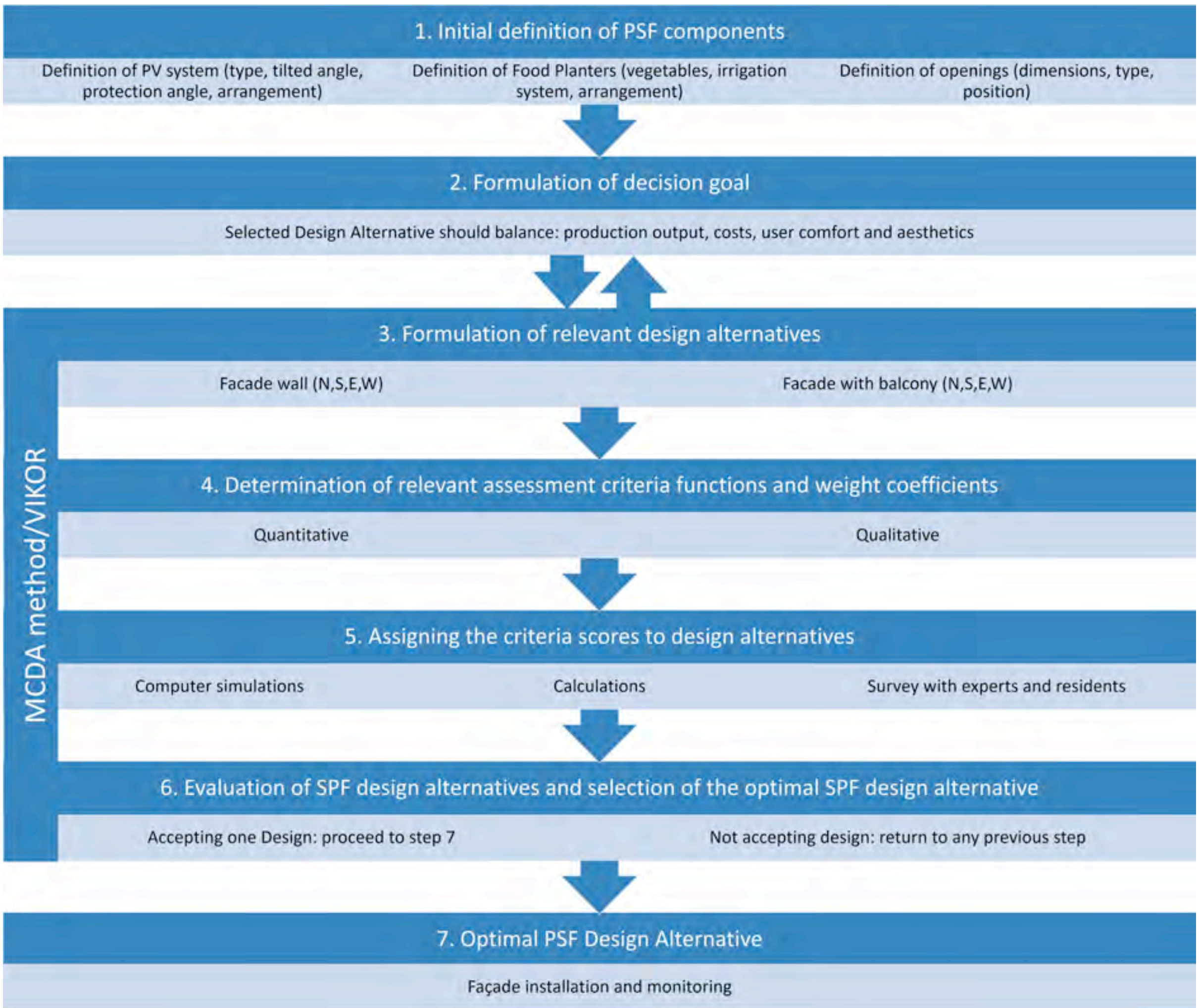

Figure 1. Productive Solar Façade (PSF) systems development and optimisation methodology

Design alternatives

Figure 2 shows a selection of design alternatives highlighting variables such as: the PV tilt angle, angle of protection, and planter's arrangements. In total, there are 980 design alternatives, 240 for the facade wall and 740 for the facade with balcony. The PV panels and planters serve as shading devices reducing solar gain. Planters with vegetables and herbs may also be used as wind-permeable railing of a balcony or corridor.

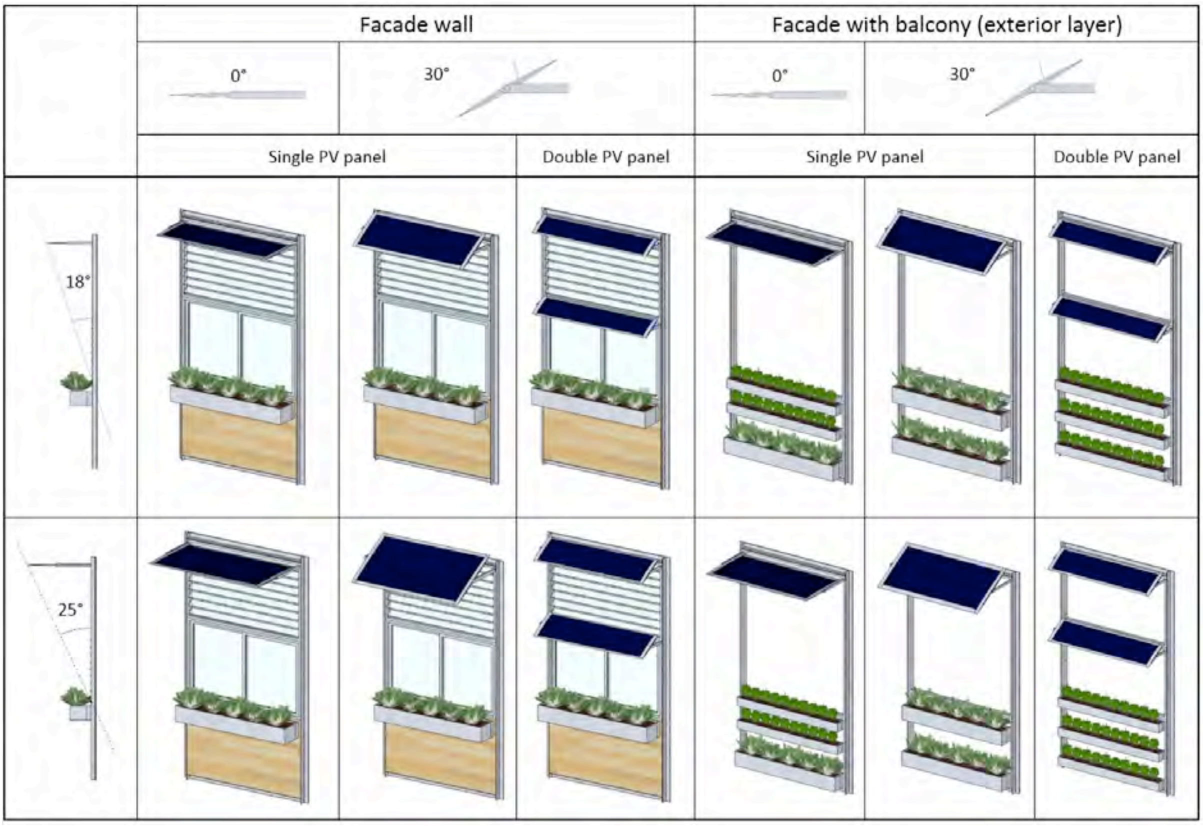

Figure 2. Selection of design alternatives for the application on the facade wall and facade with balcony. Total number of design alternatives: 980.

In terms of criteria functions such as the production yield, simulation models replicate the facade assessment for at least one level above. This is necessary since the effect of upper levels planters or BIPV on the availability of sunlight should also be taken into account. The prototype is a generic proposal; therefore, at this stage, only a low angle obstruction is considered rather than a more realistic urban morphology comprising middle/high-rise residential buildings in close proximity to the facades.

Design strategies and criteria

The MCDA comprises 10 criterion functions referring to three main criteria categories: architectural quality, production performance and financial performance (Table 1). In the first optimisation, criteria function groups are given the same weight coefficient (ω_i) (0.1 each). Metrical units used in evaluation are also specified as well as the expected best performance (Ext, Minimum or Maximum).

Since the facade prototype is to be installed at a test-bed facility, the ease of transportation and installation is also considered. This aspect is aligned with the need for the systems to be installed as a retrofitting measure in existing buildings. Other features such as: usability, acceptance, and aesthetical value, aim to address user-oriented aspects also pertaining to the actual use and success of the proposed systems.

Table 1. Criteria categories, criteria function groups and individual criteria functions for PSF design alternatives evaluation. 'ω_i' and 'Ext.' refer to the weight coefficient and to expected best performance respectively.

Criteria categories	Criteria function groups		Individual criteria functions	f_i	Units	ω_i	Ext.
Architectural quality	Functional quality	Daylight performance (0.1)	Daylight Autonomy (indoors)	f_1	%	0.05	Max
			Energy on lighting (indoors)	f_2	KWh	0.05	Min
		Thermal performance (0.1)	Envelope Thermal Transfer Value (ETTV)	f_3	(W/m^2)	0.1	Min
		Natural Ventilation (0.1)	Ventilation rate	f_4	m^3/s	0.05	Max
			Wind speed	f_5	m/s	0.05	Max
		Views quality (0.1)	Angle of view/opening	f_6	degrees	0.1	Max
		Usability & Acceptance (0.1)	Accessibility	f_7	qualitative (1-5)	0.05	Max
			Residents' acceptance	f_8	qualitative (1-5)	0.05	Max
	Aesthetic quality (0.1)		Aesthetic quality of the element	f_9	qualitative (1-5)	0.1	Max
	Constructive quality (0.1)		Components' weight	f_{10}	kg	0.05	Min
			Ease of assembly/disassembly	f_{11}	qualitative (1-5)	0.05	Max
Production performance	Energy yield (0.1)		PV electricity generation per year	f_{12}	KWh	0.1	Max
	Food yield (0.1)		Total value of produced food	f_{13}	SGD	0.1	Max
Financial performance	Costs (0.1)		Installation costs	f_{14}	SGD	0.05	Min
			Maintenance costs per year	f_{15}	SGD	0.05	Min

In terms of the production performance, criteria were defined per energy yield and food yield. For energy generation, the standard metric unit used to assess the BIPV performance is the total electricity in KWh. In terms of food production, rather than the total weight (kg), the total value of the produced food (SGD) was considered to be more relevant seeing how, while herbs and vegetables may not be very heavy, they still constitute a valuable output for residents and provide a significant incentive for cultivation.

Safety was another criterion under consideration; however, since all design alternatives should comply with minimum safety standards, it was not included in the MCDA. Once the SPF prototype optimisation is resolved, the criteria and weight coefficients will be chosen by authors in cooperation with the local building authorities and experts from the PV industry and research institutions. Grasshopper's plug-ins software is used for the calculations of the criteria functions values related to daylight performance, thermal performance, natural ventilation, and electricity production. A numerical grade on the scale from 1 to 5 is assigned to design alternatives with regards to qualitative criteria such as: accessibility, residents' acceptance, aesthetic quality and ease of assembly/disassembly. Also, the component's weight and costs will be estimated. With regards to design alternatives aesthetic qualities, a survey will be carried out among public housing residents, university staff, architects, engineers, and PV experts.

Selection of optimal design alternatives

The VIKOR method relies on the weight coefficients of the criteria functions to model the preferred structure of a design strategy. The selection of the optimal design alternative refers to the value Q_j, Eq. (3), as the value that ideally approximates the balance i.e. the compromise between two decision-making strategies:

(1) Maximum group benefit (better alternatives are good according to the majority of criteria) - as defined by S_j, Eq. (1) and

(2) Minimum of maximum deviation of ideal value (better alternative must not be very bad according to any criteria) - as defined by R_j, Eq. (2) (Opricović and Tzeng, 2004).

The VIKOR algorithm (Opricović and Tzeng, 2004) follows several steps in order to reach a compromise between J alternatives: $A1, A2, \ldots, A_J$ as per the established n criteria functions f_i and their relative importance stated through criteria functions weight coefficients ω_i.

The first step determines the best f_i* and worst f_i^- values for each criteria function. The second step calculates values S_j, R_j and Q_j in the manner stated below:

$$S_j = \sum_{i=1}^{n} w_i \left(f_i^* - \mathrm{f}_{ij}\right)/\left(f_i^* - \mathrm{f}_i^-\right), i = 1,2,\ldots,n,\ j = 1,2,\ldots,m, \tag{1}$$

$$R_j = \max_i [w_i \left(f_i^* - \mathrm{f}_{ij}\right)/\left(f_i^* - \mathrm{f}_i^-\right)], i = 1,2,\ldots,n,\ j = 1,2,\ldots,m, \tag{2}$$

$$Q_j = v(S_j - \mathrm{S}^*)/(S^- - \mathrm{S}^*) + (1 - \mathrm{v})(R_j - \mathrm{R}^*)/(R^- - \mathrm{R}^*),\ j = 1,2,\ldots,m, \tag{3}$$

whereas

$$S^* = \min_j S_j, S^- = \max_j S_j,\ j = 1,2,\ldots,m, \tag{4}$$

$$R^* = \min_j R_j, R^- = \max_j R_j,\ j = 1,2,\ldots,m, \tag{5}$$

Value v represents the weight relative to the maximum group utility strategy and *(1-v)* stands for the individual regret weight. Based on the above calculations, three ranking lists are obtained that determine the order i.e. the rank of the alternatives. The lists are sorted according to the descending values of *S*, *R,* and *Q* values. The compromise solution is the alternative with the lowest Q value indicating “acceptable advantage” and “acceptable stability” (Opricović and Tzeng, 2004).

The VIKOR method allows both the criteria and weight coefficients to be changed relatively easily. This also helps analyse the criteria and weight coefficients impact on the compromise solution, and provides a clearer insight into the selected solutions.

Preliminary results

Currently, only the preliminary results from an independent evaluation of BIPV and vertical farming systems are available.

With regards to the BIPV on the facade wall solutions, a 30° tilt angle of PV panels that also serve as shading devices, is considered as the optimum angle for north and south facades accounting for the incident direct and diffuse sunlight. This tilt angle applies to all levels of a multi-storey residential building with different sky view factors involved. Horizontal position as the optimum position for obtaining maximum yield, solar protection, and daylight levels is considered only at the top level. As for the arrangement of the PV panels, a double panel system is preferable over a single panel. This is applicable for frameless modules or modules with minimal frames (Ong and Tablada, 2017).

Regarding the application of vertical farming arrangement on the facade with balcony, the best output is provided with three rows of planters, preferably two rows for larger vegetables and one row for smaller ones, not only in terms of the yield, but also in terms of accessibility. Facade arrangements for east and west orientations would require larger overhangs or narrower spacing between louvers in order to provide protection from direct sunlight. However, other important design features such as: daylight, views towards outside, and overshadowing between the BIPV and planters would be affected.

Conclusions

This paper describes the methodology applied in the development and optimisation of modular productive facade prototypes that integrate BIPV and BIA systems in residential buildings in Singapore. The presented framework gives systematic guidelines that lead to optimal SPF solutions. Each facade prototype is analysed for its implementation on the facade wall and facade with balcony and optimised for north, south, east, and west orientations. Facade modules will be installed and tested at the T^2 Lab, at the NUS Kent Ridge Campus.

VIKOR as the MCDA method, is recommended for finding the optimal SPF solutions for four facade orientations and helps understanding how different optimisation requirements influence optimal solutions as well as the reasons behind them. The VIKOR method was applied in order to optimise eleven quantitative and four qualitative criteria functions. Since architectural integration of the optimal element selected is of high importance, the criteria related to architectural quality have greater weight coefficient in terms of the optimisation. Distribution of criteria weight coefficients can however be easily altered and adjusted to meet different project requirements. For instance, the project owner could require that facade costs have a higher weight in comparison to the production performance.

The recommendations given in this study on the optimal arrangements, geometrical forms and types of PSF elements contribute to the discussions on solar architecture and the integration of renewable resources into urban and building design in order to reduce the dependency on fossil fuels and the current carbon footprint in tropical regions.

Acknowledgements

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Design to Thrive

Seeing the miraculous in the common: Re-mainstreaming the use of sustainable building materials

Dr Keith Baker[1] & Dr Craig Thomson[1]

[1] Built Environment Asset Management (BEAM) Centre, School of Engineering and the Built Environment, Glasgow Caledonian University, Glasgow, Scotland. E. keith.baker@gcu.ac.uk

Abstract: Europe is in danger of losing much of the knowledge and skills needed to sustain the traditional industries that supply natural and sustainable materials and products to architects, the construction industry and housebuilders. This paper describes the outcomes and knowledge developed as part of the Natural Energy Efficiency and Sustainability (NEES) Project, funded by the European Regional Development Fund's Northern Periphery Programme and delivered by partners across Scotland, Ireland, Northern Ireland, Sweden and Greenland. The project focused on the development of the 'NEES Process' to identify and promote fifteen examples small to medium-sized enterprises demonstrating best practice in the use of natural and recycled building materials sourced from Northern Europe. As well as being exemplars of energy and / or resource efficiency the NEES Best Practices were also selected for being sensitive to local architectural heritages, cultures, and traditional industries. As part of this project a number of key opportunities and barriers for increasing the take up of locally-sourced sustainable materials, products and services were identified; including the potential co-benefits to other sectors, the need to stem the loss of traditional knowledge and skills, and the litigious nature of some larger producers of conventional building products and materials. This paper also describes the knowledge and practice gaps that need to be closed in order to reintroduce and mainstream the use of traditional and sustainable building materials into architectural practices and public procurement policies, and from there to re-mainstream their use by local tradespeople and householders. Finally, it questions the value of the government led agenda for innovation in building materials where natural and traditional materials can offer equal, or near equal, levels of energy efficiency whilst providing additional co-benefits to householders, local communities, the environment, society, and regional economies.

Keywords: sustainable, natural, building, materials, energy efficiency

Introduction

The critical importance of realising sustainability and the central role of the built environment in achieving this is recognised at the highest levels (UN Habitat, 2008; European Commission, 2007; WCED, 1987). However, current sustainability assessment protocols are largely confined to assessing the environmental performance of buildings and fail to address their impact on quality-of-life and the interrelationship between the two thus not optimally aligning with the principles of sustainable development. Even within the current environmental focus, the emphasis is often on a narrow range of issues such as energy performance (for example, The Energy Performance in Buildings Directive – European Commission, 2002) and material use ("Environmental Product Declaration" EPD, 2008). As such, sustainability in its widest sense of delivering quality-of-life while improving environmental performance, is yet to be fully operationalised because existing assessment tools and protocols are insufficient for capturing these 'co-benefits' (Pridmore et al., 2017).

In this paper we present the philosophy behind the criteria development and evaluates the results obtained in selecting and accrediting sixteen examples of Best Practice as part of the European Regional Development Fund's Natural Energy Efficient and Sustainability (NEES) Project (NEES, 2016).

Background

Despite their shortcomings, a plethora of sustainability assessment methods (SAM's) have emerged recently. As early as in 2005 Walton et al (2005) identified that there were over 600 tools dealing with one or more aspects of sustainability in buildings. Despite the abundance of tools, the landscape is incomplete in its coverage of sustainability themes, with no one sustainability assessment tool providing complete coverage and the criteria around which the method is developed, often reflecting variations in their interpretation of the concept. Poston et al. (2010) conducted a comparison of the thirty most commonly used SAM's to explore the coverage of their criteria against a holistic interpretation of sustainability. The findings of the survey confirmed the incomplete coverage of criteria against economic, environmental and social themes and confirmed a tendency to focus on environmental impacts often from a technical standpoint, thus failing to account sufficiently for cultural and economic considerations which are important to the aim of the NEES project.

In establishing the basis for an assessment criteria for selecting best practice products and services based on the principles of the NEES project, there was a need to go beyond what is commonly reflected within the criteria used by common sustainability assessment tools. We therefore considered established criteria within common tools, criteria emerging within tools which reflect novel articulations of sustainability, and drew on sustainable material frameworks such as NaturePlus™ (NaturePlus, 2017) for validation.

Method

Our approach drew on the experience of the SUE-MoT research project (SUE-MoT, 2008) involving Glasgow Caledonian University (GCU) which developed a criteria for assessing sustainability of building projects. This criteria was tailored for the context of sustainable materials and cross mapped with the criteria displayed in novel articulations within SAM's (Poston et al. (2010) and drew on a sustainability materials selection criteria developed by GCU with a housing development team and housing association. The emerging materials selection criteria was developed around bioregional principles but was established from the same reductionist approach. The criteria embodied many of the environmental principles reflected in NEES, but a need existed to tailor the criteria to reflect the future potential of the product or service within the market and the context of the Northern Peripheral Programme (NPP) regions (geographic, cultural, economic, skills and traditions). The emerging criteria was validated through comparison with the NaturePlus™ criteria (NaturePlus, 2017) which focused on the technical elements of resource efficiency, environment and health criteria; but were found to lack the wider sustainability, enterprise and scalability criteria important to NEES.

Consultation with the NEES partners and stakeholder experts was an important element of the refinement process with a view to ensuring the emerging assessment criteria met with the principles pursued within the project, best practice and to enable regional variations to be reflected (i.e. Scotland, Ireland, Northern Ireland, Sweden and Greenland). This process aided in establishing a firm understanding of the NEES philosophy and its articulation in the context of the criteria. An expert panel was convened comprising of professionals in sustainable design and construction from the different partner regions. They provided technical input, and ensured that the emerging criteria reflected the latest interpretation of best practice to sustainable materials within their regions.

Emerging from this was an aim for NEES to seek to promote products which “were comprised of a minimum of 85% of renewable raw materials, or mineral based materials which are almost unlimited in their availability”. The synthetic or high-tech components of such products were strictly limited and reduced to the minimum level that is technically possible. Harmful emissions were avoided and on the other, and the use of fossil fuels and limited natural resources were minimised. The origins of the raw materials were carefully checked. NEES also seeks to promote services if they “were based on the use of such products, and their implementation has no or limited environmental impact”.

To ensure that products and services considered for selection as Best Practices meet this philosophy, three ‘gateway’ criteria were introduced to eliminate quickly failing submissions from the process:

- Use of natural and / or recycled materials
- Suitable for retrofitting to improve the energy performance of buildings
- Sourced from the NPP region, or those with main market in the region.

Those products and services that meet all three of the gateway criteria are then scored against five NEES assessment criteria (Table 1). The first two criteria aligned with the NaturePlus criteria, the findings of the SUE-MoT project and the sustainable building materials criteria developed by GCU. The third expands these to cover a wider definition of sustainability incorporating social, cultural; heritage aspects and wider economic impacts, and the latter two are more blunt assessments of success and future market potential. On passing the three ‘gateway’ criteria, representatives of the products and services were asked to submit an application for consideration as a promoted best practice through the NEES website. The application was in the form of an online survey designed according to whether the applicant provides a product or service. The product survey set specific questions designed to draw out pertinent information that may not be obvious to applicants. The initial version of the services survey was simplified following feedback from respondents and the expert panel. The survey then focused on requesting case studies that address the ‘natural / recycled’, ‘energy efficient’ and ‘sustainable’ aims of the project.

Table 1. The NEES Assessment Criteria

Criteria	**Aspects of sustainability assessed**
Resource efficiency	This captures the more quantifiable impacts of the products and services, including life cycle costs, carbon footprint, and energy savings attributable to use
Environment and health	This captures less directly quantifiable impacts such as pollution and any hazards to human health (from installation and use)
Sustainability	This captures socio-economic impacts as well as cultural issues such as sensitivity to regional architectural traditions
Enterprise	This captures the growth, to date, of the product or service (given that all applicants must be SMEs or smaller)
Scalability	This captures the potential for growth, including the sustainability of the product or service if demand were to grow significantly, as well as the value that could be added by involvement with the project.

In line with the Delphi Process (Dakley & Helmer, 1963) the completed assessments were passed to a panel of independent experts (one representing each partner region) to score and evaluate against a standard marking scheme. The results were collated, the highest and lowest marks removed, and the average of the remainder taken. Those scoring above or below 7 under all five criteria are automatically accepted or rejected and the rest were further evaluated at a meeting of the panel, who had the option of accepting, rejecting, or referring a submission back for (specific) information. The whole process is therefore designed to eliminate professional bias, minimise the time needed from experts, and facilitate more detailed discussion where this is needed regarding the characteristics of the NPP regions. The panels were established partly to overcome the research/ information gap surrounding the performance of products and services aligned with the NEES criteria and to ensure professional opinion and experience within the NPP regions was reflected.

Outcomes and Discussion

Table 2, on next page, details the Best Practices and the main reasons for their selection by the panel. In Scotland and Ireland there was observed a high proportion of submissions from small micro-enterprises which displayed limited business skills and resources to grow their product and business. A committed community of architects providing sustainable design services was represented but reported a real challenge finding suppliers within the local area for sustainable materials. Both these regions exist close to large urban areas (central belt of Scotland; Dublin and Belfast in Ireland) which can service this market with products and services resulting in an abundance and dominance of contemporary materials.

In Sweden, the submissions were largely from large companies who have invested in developing products with a view to promoting these on the Swedish and global markets. Due to low population levels the potential for commercial activity servicing a local market is limited and this is reflected in the lack of micro enterprises promoting products and services.

In Greenland, the submissions reflected challenges in obtaining submissions from this region resulting in an inability to identify a successful Best Practice. This reflects the reliance on imported building materials from Denmark and limited economies of scale for local products and services. A lack of local training and investment problems associated with investment levels required for research and development of materials suitable for the Arctic climate were observed. Economies of scale were identified to be a common barrier limiting the potential for growth in all regions. Low population density in Greenland and Sweden restricts the market potential for such products and services at a commercial level locally. Sweden relies on large organisations to invest in the region in order to promote these products to the mass market. In Scotland and Ireland, the focus is on mirco-enterprises and two types of organization were observed with 1) lacking the desire to grow due to the local scale of the business satisfying the needs of the shareholders, and 2) those that have the desire to grow but lack the skills and experience to grow their business.

The process also enabled the identification of some common barriers to mainstreaming sustainable building materials. Simple lack of awareness of their benefits (and co-benefits) amongst the construction industry, housing developers, and the public was a commonly-cited barrier, along with a lack of professional training opportunities for architects and house builders. However, where clients were aware, or made aware, they were reported to have found them preferable for reasons such as being safer for installers and more aesthetically pleasing for occupants. A potentially more significant barrier, and a key finding of the study, was the costs of achieving relevant certification for products manufactured by the smaller companies, and the potential consequences of making claims without that certification. Larger competitors using conventional products and materials were commonly viewed as being litigious towards smaller companies who promote the sustainability of their products and services, and even the risk of legal action was seen as sufficient to deter them from making such claims. This was further compounded by the financial and staff resource costs of achieving relevant certification, and the project produced an example of this.

Table 2. The NEES Best Practices

Name	Country	Materials	Reasons for selection
Advanced Timbercraft	Northern Ireland	Timber; cellulose; hemp; sheepswool; woodwool; wood fibre	Family-run firm specialising in low energy, high thermal performance buildings, using recylable and biodegradable materials
Anu Green	Ireland	Structural materials for roofing; soil / bedding material; plants / grasses	60-100% use of recycled materials; co-benefits of green roofs
Ecological Architecture	Scotland	Local, sustainable timber; hempcrete; reclaimed stone; sheepswool; etc	Pioneering and innovative ecological architectural practice established by two (female) experts
Enviroglass	Shetland, Scotland	Processes recycled glass into aggregates and paving materials	Recycles ~99% of Shetland's waste glass, which would otherwise be shipped to the mainland
Ecocel	Ireland	Processes recycled cellulose (newspapers) into blown-fibre insulation	Highly sustainable; non-toxic; suitable for retrofitting into difficult spaces; proven to provide better thermal regulation than conventional insulation
FH Wetland Systems	Ireland	Constructed wetlands; reed beds; zero discharge willow facilities	Natural and sustainable solution to wastewater treatment; reduces infrastructure energy costs
The Hollies Centre for Sustainability	Ireland	Cob; bale cob (strawbale and cob hybrid); timber; stone; clay; sand; lime; locally-sourced earth pigments	Example of a consultancy which also provides training in the use of natural building materials
Inzievar Woodlands	Scotland	Native Scottish hardwood and softwood timber	Mixed woodland managed for co-benefits – recreation, tourism, etc; sawmill is Scotland's main processor of native timber
Locate Architects	Scotland	Local, sustainable timber; hemp insulation; natural paints; Scottish linoleum;	Best practice in combining natural and sustainable materials with modern design approaches – PassivHaus, etc
MAKAR – Design and Build	Scotland	Architectural practice specialising in off-site construction using local, natural and sustainable materials	Use of local, natural and sustainable building materials; dwellings are nearly 100% recyclable or biodegradable; off-site construction using lightweight materials reduces embodied energy costs in rural / island areas
MAKAR - nSIPS	Scotland	Natural structually-insulated panels manufactured from local timber and recycled cellulose	Economically and socially sustainable - contributes to rural regeneration – has grown to ~30 staff and apprentices
Martinsons - Gluelam	Sweden	High strength locally-sourced structural timber product	Use of local timber; economically and socially sustainable in a rural region with a low population density
Martinsons - Xlam	Sweden	High strength locally-sourced structural timber product	Use of local timber; economically and socially sustainable in a rural region with a low population density
Masonite Beams	Sweden	Floor, wall and roof systems using locally-sourced timber	Use of local timber; economically and socially sustainable in a rural region with a low population density
Mud and Wood	Ireland	Cob; lime; reclaimed timber; straw bale	Example of a consultancy which also provides training in the use of natural building materials
SWECO Umeå	Sweden	Sustainable materials sourced from the region	Selected as an example of a larger company using materials certified to the highest standards

Of the smallest Best Practices, Ecocel was notable in having an important benefit (improved thermal regulation over conventional insulation) certified by testing carried out at Delft University, the Netherlands (Ecocel, 2013). Therefore, in order to meet the aim of the NEES project to support the development of small businesses and better understand barriers to growth, the project funded another of the smaller Best Practices, Enviroglass, to be assessed for the Carbon Trust's Product Footprint label, which is the UK's most established certification scheme for low carbon products (Carbon Trust, 2017). Enviroglass, which recycles ~99% of Shetland's waste glass into paving and aggregate products, and which was fending off an attempt by the Scottish Government to require this to be exported to a recycling facility on the Scottish mainland, was seen as an excellent example of a small business which should benefit from certification.

However, although certification was achieved, this proved to be an arduous process which ran significantly over-time and over-budget (the final cost being approximately £13,000 from an estimated budget of approximately £6,000, excluding staff time for Enviroglass). For this, the GCU team contracted a qualified Carbon Trust assessor, paid for the necessary software licence, and managed the contracts and relationships between the three parties. Of the many problems that befell the project the usability of the software, even for an experienced assessor, and difficulties in accessing an electricity meter caused the most significant delays and added costs. The latter was due to Enviroglass's meter being sited in locked premises next door which were rarely used by the tenant, and who proved difficult to contact, and provides a useful example of a practical problem encountered by the smallest businesses working under ad-hoc arrangements (Enviroglass employs two staff who work across the Shetland Isles), and who were typical of the applicants from Scotland and Ireland. For such a small community-based business the staff time required to achieve certification was significant, and as such the main consequence of this experience, rather than to develop a case study to encourage other small businesses to invest in certification, turned out to be exactly the opposite.

A related set of issues was raised by the experience of another Scottish Best Practice, Inzievar Woodlands. Inzievar consists of a sawmill, which processes almost all of the native hardwood and softwood timber grown in Scotland, and a woodland managed for co-benefits including biodiversity, recreation and tourism. As part of engaging the Best Practices with the project, NEES team members visited each of the businesses to interview them about issues including barriers to growing their businesses, and the interview with the staff at Inzievar produced an important observation which was also reflected by other smaller Best Practices – *"we don't want to grow, we just want neighbours"*. This comment reflects a wider critique which emerged from many of the interviews but particularly the smaller companies, that of questioning both the 'growth is good' assumption that is inherent in many political conceptualisations of sustainable development, and within this the role of 'innovation for the sake of innovation' as a driver for growth.

A more nuanced view on growth, articulated particularly by the architects, was about the quality of the jobs created by growth and the benefits of training and retaining skilled employees in rural areas. Measures to promote innovation through competitive funding were also frequently cited as a barrier to growth, in that in order companies were having to add 'something innovative' to their products and services in order to be eligible to apply for support. In some cases this had been overcome by partnering with universities, but was generally seen as an added expense that some felt would be better spent on funding retrofits using existing, proven, energy efficient products and materials.

Conclusions

The title of this paper comes from a quote by Ralph Waldo Emerson, chosen because it articulates the responses of clients of the NEES Best Practices, and of the many policy makers and members of the public who engaged with many activities carried out as part of the project. At no stage did any of the project team encounter any resistance or objections to the benefits (and co-benefits) of promoting locally-sourced, natural and sustainable building products and materials, and these have now been recognised in Scottish policy (Pridmore et al., 2017; Scottish Government, 2017).

Yet in Scotland, and to differing degrees across the European Union, much more needs to be done if we are to re-mainstream the use of sustainable building materials and avoid losing the traditional skills, and skilled tradespeople, needed to sustain these industries. As the Best Practices illustrate, these industries are highly diverse both in terms of the products and services they offer, and of the nature of the companies themselves. This means that whilst some will be receptive to conventional market-led policy responses, the needs of others may be better met through more holistic approaches to promoting energy efficiency and social and economic regeneration in rural and island areas.

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Thermal Performance of a Hemp Lime External Insulation Building: Experimental and Numerical Coupling

Georges Costantine, Chadi Maalouf, Tala Moussa, Guillaume Polidori

Thermomechanical Laboratory LTM, GRESPI, SFR Condorcet FR CNRS 3417, University of Reims-Champagne-Ardenne, 51 687, Reims, France
Georges.Costantine@univ-reims.fr, Chadi.Maalouf@univ-reims.fr, Tala.Moussa@univ-reims.fr, Guillaume.Polidori@univ-reims.fr

Abstract: Hemp-concrete is a green material obtained by mixing hemp hurds, mineral binder including lime, water and additives. Compared to classical building materials, it has a low embodied energy, a high porosity as well as interesting thermal and hydric properties. It also contributes to the reduction of energy consumption and greenhouse gas emissions. Thus, hemp-concrete becomes highly recommended in constructions and finds applications as internal or external thermal insulator in wooden frame walls. At wall scale, studies proved that using hemp-concrete in building envelope seems to improve indoor hygrothermal comfort. In that context, a French building in Champagne-Ardennes region, employing hemp-concrete as external insulation is selected and studied. An apartment is monitored for several months. Indoor temperatures, relative humidities, thermal heat flux as well as external weather conditions are measured using sensors installed inside the apartment and a weather station at the roof of the building. Measurements underline the hemp-concrete ability to dampen external weather conditions by showing satisfactory results for indoor temperature and relative humidity. Experimental approach is then coupled with a numerical validation at the wall scale using SPARK simulation tool. Investigations are conducted on thermal heat flux through the wall. Results show a good agreement between numerical values and experimental measurements.

Keywords: hemp-concrete, experimental measurements, numerical simulation, SPARK

Introduction

Due to the high dependency of human's activities on fossil energy, several environmental issues related to the depletion of natural resources began to threaten the world growth on the beginning of the 21st century. Therefore, turning into renewable resources seems to be a plausible and interesting solution in order to provide a sustainable development. In that context, the building sector is highly concerned, since buildings are known by their high consuming energy rate (43%). Thus, innovative eco-friendly materials, such as Hemp-concrete, have become a new trend in modern constructions.

Hemp cultivation is widespread in many countries of the European Union. France is considered as the major producer, particularly the Grand-Est region, which makes this source affordable in terms of elaboration and transportation fees. The Hemp-concrete technology has appeared in France in 1987 and its composition depends on the application type: internal or external insulator, wall, roof … Several studies in this field proved the interesting properties compared to classical building materials (aerated concrete, hollow brick, …): a low density (between 450 and 700 kg/m^3) making it a light weight material, and high porosity which can reach 70% of its volume (Collet 2004) (Evrard 2008) . The low thermal conductivity and diffusivity allow the Hemp-concrete to dampen external temperature variations. Moreover, Hemp-concrete is classified as excellent hydric regulator due to its high moisture buffering value (MBV >2). However, mechanical properties showed that it is not suitable to be used as load bearing material but could be associated with a wooden frame.

Plentiful works are carried out at the wall scale dealing with Hemp-concrete hygrothermal behavior when subjected to different temperature and relative humidity variations. In this field, several aspects are studied: the influence of the Hemp-concrete hysteresis on the heat and mass transfers within the wall (Lelievre et al. 2014)(Costantine et al. 2016), the effects of sorption isotherms thermal dependency (Le et al. 2015) … However, till now, the literature presents a lack of investigations at the building scale.

In this scope, this work aims to evaluate the thermal performance of a building using the Hemp-concrete as external insulator. For this, an apartment of this building is selected to be studied. Experimental devices are implemented to measure external weather conditions, indoor air temperature and relative humidity, as well as the thermal flux through the south building façade. The indoor comfort is also analyzed. Results show satisfactory conditions in the apartment and highlight the impact of the inhabitants' behavior with respect to their apartment. Moreover, a numerical validation is conducted on thermal flux through the wall via the simulation tool SPARK. Comparison shows a good agreement between the experimental data and the numerical results.

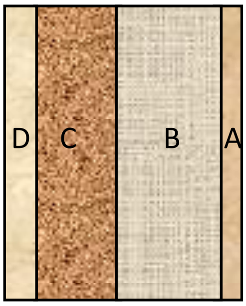
Methodology

Building overview

Figure 1: view of the North façade of the building

A building located in Fleury-La-Rivière, a small town in the Champagne-Ardenne region, is chosen for the study. It consists of three floors with six apartments and is oriented in such a way to maximize the exposure to direct sun rays. The envelope is composed of four layers which are detailed in Table 1 where the Hemp-concrete, sprayed into the walls, is used as external insulator. Materials properties are provided by the constructor. Apartments are equipped with electrical heaters and mechanical ventilation is used for air renewal.

Table 1: Properties of the building envelope layers



2 cm 13 cm 20 cm 1.5 cm
D: outermost surface

Material	Density ($Kg.m^{-3}$)	Thermal Conductivity ($W.m^{-1}K^{-1}$)	Heat Capacity ($J.Kg^{-1}°C^{-1}$)
A : Gypsum	900	0,25	850
B: Optibric	700	Req=1,07	850
C : Hemp-concrete	450	0,095	1000
D : Lime-sand plaster	1650	0,4	830

Experimental approach

Thermographic survey

Building envelope is inspected from the internal and external sides using infrared thermographic technic able to detect the constructions defects and eventual thermal bridges in the structure. For this, an IR FLIR SC620 camera (FLIR system, Wilsonville, OR) with a high resolution pixel detector (640×480 pixels) is used. Emissivity of the walls is set at 0.95 during the thermographic survey. Wall captions were performed in April 2015 early in the morning and, in September 2016 in the evening. These chosen dates guarantee a wide gradient of temperature between inside and outside.

External weather conditions

A weather station shown in Figure 2 is installed at the building roof in order to record external weather conditions. It is equipped with an Integrated Sensor Suit (ISS) to measure external temperature, relative humidity, solar radiations, wind speed and directions as well as rainfall rate. Time step is set to 30 minutes. Data is transmitted via a wireless connection and stored in a console receptor. Measurements were launched in November 27, 2015 until September 28, 2016.

Figure 2: Weather station of type Vantage Pro2 installed outside the building

Apartment monitoring

The study begins with a survey on the internal comfort in the apartment. The encountered problems were related to the high humidity and air leakage in the rooms. A mould development was also observed at the floor level. The selected apartment is a ground floor of 92.30 m^2 composed of four rooms (office, two bedrooms and a living room), a kitchen and a bathroom.A family of three members with two dogs live there.

Four thermohygrometers (TH BeanDevice), installed in the apartment rooms, measure dry temperature (°C) and relative humidity (%) of the indoor air. Three temperature globe sensors (T BeanDevice) also record the wet bulb globe temperature in three rooms except the kid’s room. Moreover, three thermal flowmeters are fixed at the south west office wall: one is placed at the ground level, and the others at a height of 1.20 m (Table 2). Flowmeters measure the thermal losses through the envelope (W/m^2). Data is monitored continuously from November 27, 2015 until September 28, 2016 with a time step of 15 minutes. It should be noticed that slight cracks are identified on this façade near the window.

Table 2: Experimental devices implemented inside the apartment

		
Thermohygrometer	Temperature sensor	Thermal flowmeters
Precision: ± 0.2 °C, ± 1.8 %	Precision: ± 0.1 °C	Precision: ± 5%

Numerical approach

South-west façade hygrothermal performance is simulated with SPARK numerical tool. SPARK is an object-oriented software that is very useful to solve differential systems equations using finite-difference method. Weather data is entered as inputs to the code. The approach proposed by Philipe, De Vries and Mendes to model heat and moisture transfers in hygroscopic materials is used. Moisture transport coefficients are calculated based on Crauss et al. works. Investigations are conducted on heat flux (thermal losses) through the office wall.

Results and discussions

Building envelope inspection

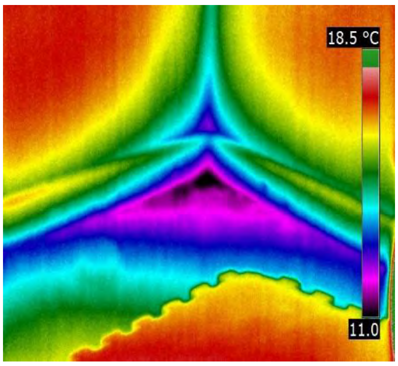


Figure 3 : Thermogram of parents bedroom inside corner

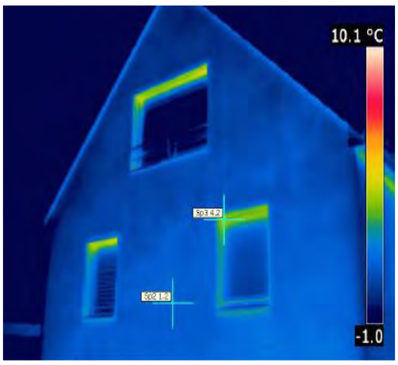


Figure 4 : Thermogram of east building façade

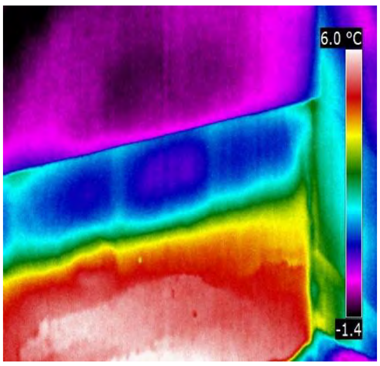


Figure 5 : Thermogram of building south-west façade

Figures 2, 3 and 4 show thermographic images of the internal and external building walls. One can observe that exterior surface temperatures are globally homogeneous. Heat losses appear at windows joints and air vents as well as the slab and floor level. This is an external insulation characteristic where insulator layer is cut at the ground level to avoid capillarity phenomenon. No thermal bridges due to timber framework are observed.

Indoor comfort analysis

The indoor comfort evaluation is performed using psychrometric chart for the different rooms. For this purpose, operative temperature (T_o) is calculated based on dry air temperature (T_a) given by thermohygrometers and the radiant temperature (T_r) deduced from globe temperature measurements (T_g). Calculation method is detailed as follows:

$$T_o = T_a + (1 - A)(T_r - T_a)$$

where *A* is a constant parameter depending on indoor air wind speed (v) :

$$\begin{cases} A = 0.5 \left(v < 0.2\, m.s^{-1} \Rightarrow \text{winter} \Rightarrow \text{closed windows}\right) \\ A = 0.7\ (v > 0.6\, m.s^{-1} \Rightarrow \text{summer} \Rightarrow \text{open windows}) \end{cases}$$

T_r is given by:

$$T_r = \left[\left(T_g + 273\right)^4 + \frac{1.1 \times 10^8 . v^{0.6}}{\varepsilon . D^{0.4}}\left(T_g - T_a\right)\right]^{\frac{1}{4}} - 273$$

$\mathcal{E}$ is the globe sensor emissivity and *D* its diameter in meters.

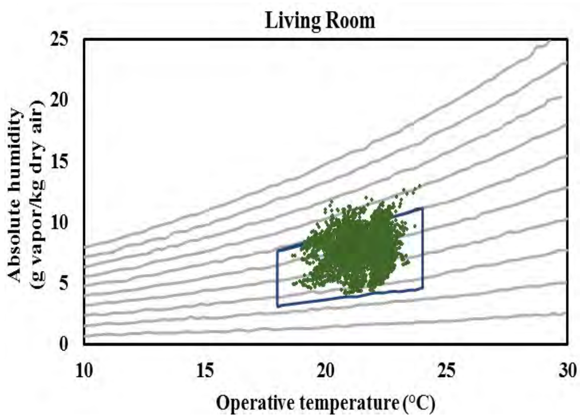


Figure 6: Psychrometric chart for the living room during winter season

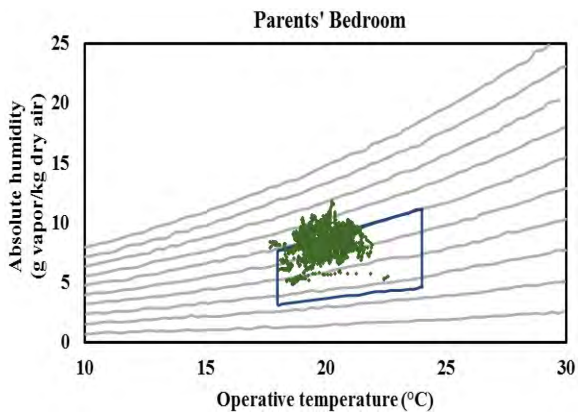


Figure 7: Psychrometric chart for the parents' bedroom during winter season

For simplicity reasons, Figures 6 till 9 present the results during winter and summer periods only for the living room and parents' bedroom. Referring to ASHREA standards, winter comfort zone is located between 18°C and 24°C for temperature and 25% to 60% for relative humidity. Otherwise, for summer period, comfort zone is defined as follows: temperature is allowed to fluctuate between 22°C and 27°C with a relative humidity between 40% and 60%. It can be noted that in terms of humidity, results are satisfactory but relative humidity reaches 70% several times in the living and parents rooms. This can be explained by the fact that kitchen is always opened to the living room and cooking activity usually occurs with a closed air vent. In addition, the laundry is dried inside the living room most of the time.

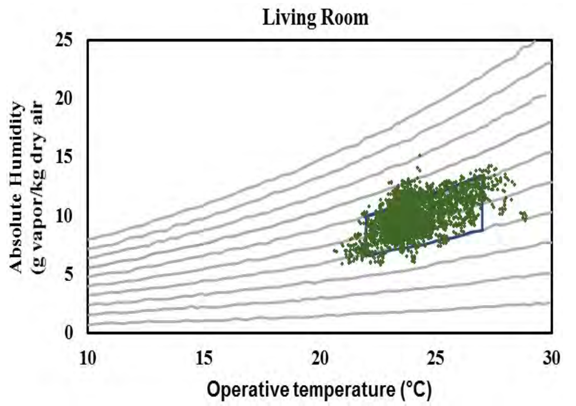


Figure 8 : Psychrometric chart for the living room during summer season

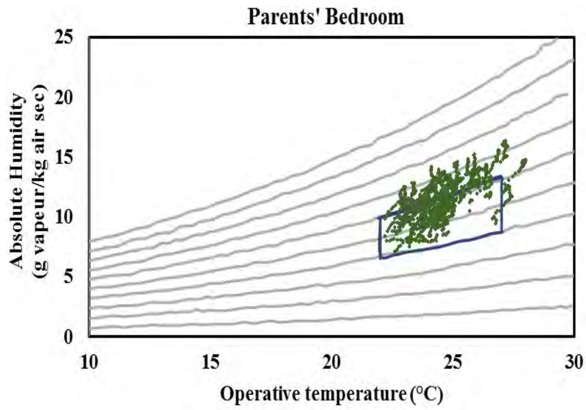


Figure 9 : Psychrometric chart for the parents' bedroom during summer season

For the parents bedroom, occasionally aerated, high humidity rates are observed: dogs are a non-negligible source of air moistening. Therefore, temperature comfort conditions are globally respected. During summer, the temperature exceeds sometimes 27°C: this could be explained by the heat waves period where external temperature reaches 40°C. This result highlights the Hemp-concrete ability to dampen external temperature variations since indoor temperature peaks are delayed about four to five hours in comparison with the outdoor peaks as seen in Figure 10.

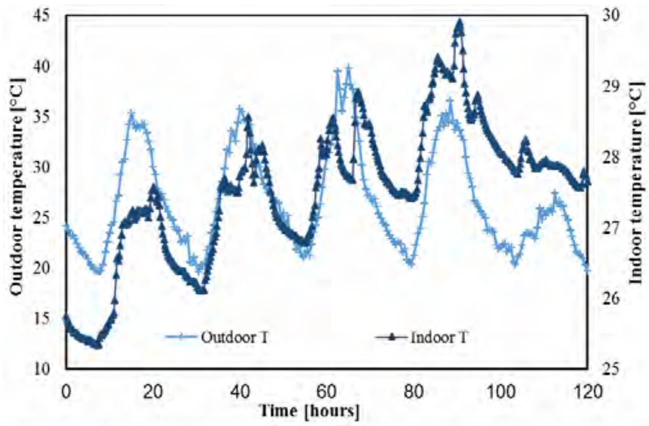


Figure 10 : Comparison between indoor and outdoor temperatures between August 20, 2016 and August 25, 2016

Experimental and numerical investigations on the thermal losses through the office wall

It should be mentioned that, at the beginning of the study, turning on the registration for three connections simultaneously exhausts rapidly the device's battery so that data were recorded for the first and the second flowmeter, then, in the next period, for the flowmeters 1 and 3. For the first period, Figure 11 shows a homogenous thermal flow over the height of the wall, whilst, in the second, thermal losses measured by flowmeter 3 (Figure 12) are greater than the losses measured by flowmeter 1. This is due to the third flowmeter position at the mid of the wall and exposed to wind and heavy rain. The latter can raise the wall thermal conductivity as well as the heat losses within the envelope. However, in both cases, thermal flow respects indoor temperature dynamic variations since it is proportional to the temperature gradient between inside and outside.

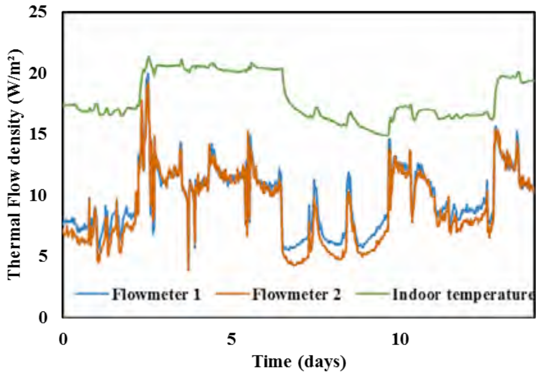


Figure 11: Experimental thermal flows and temperature in the office (Dec. 1st – Dec.15th 2015)

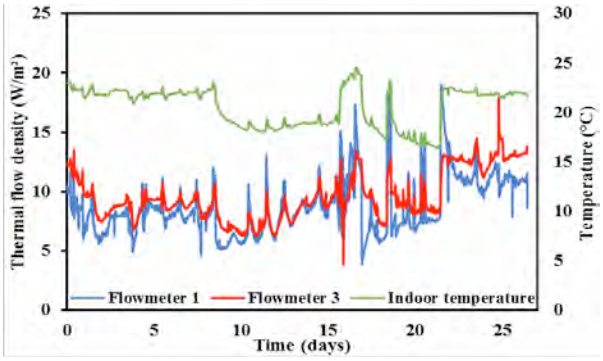


Figure 12: Experimental thermal flows and temperature in the office (Dec. 16th 2015 – Jan.11th 2016)

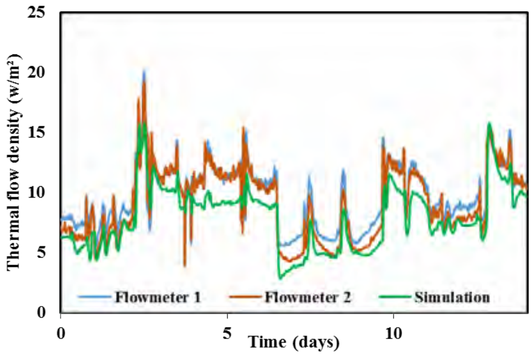


Figure 13 : Comparison between experimental and numerical thermal flows in the office (Dec. 1st – Dec.15th 2015)

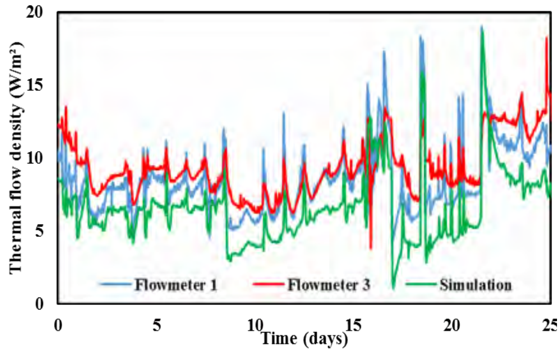


Figure 14 : Comparison between experimental and numerical thermal flows in the office (Dec. 16th 2015– Jan.11th 2016)

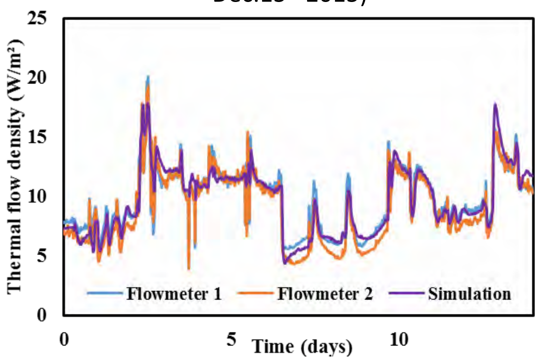


Figure 15 : Comparison between experimental and new numerical thermal flows in the office (Dec. 1st – Dec.15th 2015)

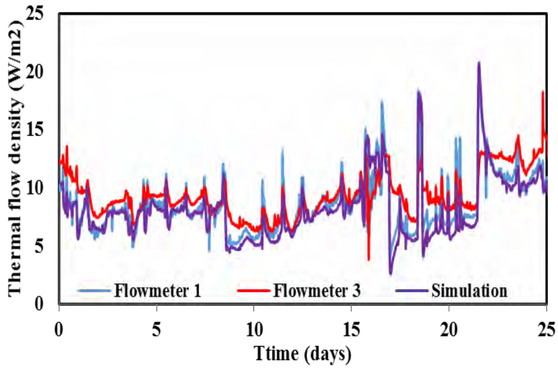


Figure 16 : Comparison between experimental and new numerical thermal flows in the office (Dec. 16th 2015 – Jan.11th 2016

Figure 13 and Figure 14 show a comparison between numerical and experimental heat fluxes through the wall. It can be observed that simulation underestimates globally the experimental measurements. The discrepancies could be explained by the uncertainty on the materials properties given by the constructor: for instance, thermal conductivity of the dry Hemp- concrete is about 0.095-0.1 $W.m^{-1}.K^{-1}$, while literature shows that this value could be much greater when Hemp-concrete is wet and can reach 0.18 $W.m^{-1}.K^{-1}$ (Collet & Pretot 2014). Therefore, taking into account the cracks in the façade, and the exposure of the wall to wind and rain, a thermal conductivity of 0.16 $W.m^{-1}.K^{-1}$ is more suitable. New numerical results show good improvements in comparison with the experiments as shown in Figure 15 and Figure 16.

Conclusion

In this work, a study of a hemp-lime building located in the north-east of France is proposed. The envelope presents a layer of 13 cm Hemp-concrete, used as external insulator. An apartment is selected to be the object of the study. A specific experimental equipment is implemented inside and outside to monitor comfort conditions in the different rooms. A numerical investigation is then conducted on the heat losses through the building south-west façade.

The results show satisfactory thermal comfort in the apartment, and some high relative humidities are detected due to the inhabitants behavior with respect to their apartment. They highlight also the Hemp-concrete ability to dampen outdoor temperature variations. Moreover, simulations present good agreement with the experimental data. However, a particular attention on the materials properties lead to an improvement in the results. No important thermal bridges due to timber framework are identified with the infrared thermography. Further observations are required on the cracks in the South-West façade to identify their effects on the envelope thermal conductivity. Globally, the Hemp-concrete insulation in this building seems to be efficient and the problems encountered are not related to the use of this bio-based material in the structure.

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A new printed and spatially transformed ETFE foil provides shading and improves natural light and thermal comfort for membrane structures

Jan Cremers[1], Hannes Marx[1]

[1] Department of Architecture and Design, Hochschule für Technik Stuttgart (HFT), Stuttgart, Germany, jan.cremers@hft-stuttgart.de

Abstract: Standard membrane structures using ETFE foils have a very high solar transmission (a single layer of typical transparent ETFE foil > 93%). Regarding façade and roof applications this can result in serious problems with overheating and also causes a high degree of thermal discomfort. The presented new shading approach is inspired by the widely used architectural idea of the shed roof (saw-tooth roof). By using this geometrical idea with foils on a much smaller scale, the direct sunlight is blocked off, whereas the steeper surface is oriented away from the direct solar radiation and allows for diffuse sunlight in with a high visual transmission of about 92% (transparent ETFE foil) [1, p.114f],[2]. The printing pattern can be adjusted considering the sun´s position and the direct sunlight radiation. This also leads to an improvement with regard to light quality and glare risk inside the room. Samples of the new foil type have been manufactured in lab-scale to investigate different combinations of printing and geometry. Compared to a conventional system (flat foil, fritted/printed), the new spatially transformed ETFE foils with an optimized adaption of the printing patterns and geometry are examined to quantify the maximum cooling energy saving potential by using dynamic thermal simulations. Also, the effect on thermal comfort and the daylight quality is investigated.

Keywords: ETFE, membrane structure, solar shading, thermal comfort, daylight quality

Introduction

Building structures using textile fabrics or foils for the envelope are referred to as membrane structures. Polymer foils such as ethylene-tetra-fluoro-ethylene (ETFE) are implemented for roofs and façade areas but also for less complex applications such as weather- and sun protection. Typical foil thicknesses for this applications range from 100µm to 400µm. Due to the extremely low mass of ETFE foils (approx. 350 g/m² @200µm) and the high transmission in the visible and solar range (one layer ETFE clear > 92% @200µm) ETFE is an alternative to glass. [1, p.114f] [2]

Key design advantages are the aesthetic potential, the large possible span widths, the safe and low-effort application in overhead-situations (cp. to glass) and a short building time. Further benefits of large areas with translucent materials might be increased solar gains in winter with a maximum of visible transmission. However, the risk of overheating and glare effects without an appropriate sun protection in the summer case is very high. This leads to uncomfortable thermal- and visual conditions inside the building [5]. For these reasons, different options exist to minimize overheating and glare due too high luminous intensity. ETFE foils can be printed (fritting) e.g. with colours (silver) which have a high reflection capacity or tinted materials can be used in several colours. Optical properties can be controlled to some extent by the pigmentation grades and printing patterns. This influences the transmittance [τ], reflectance [ρ] and the absorption [α] coefficients. The major common disadvantage of available shading solutions for foils is the fixed transmittance coefficient regardless of the incidence angle of the sun. Another additional solution is an actively switchable sun protection for membrane cushions, where the offset of two top layers with raster graphics can be switch via air pressure changes. Thereby, the solar heat gain coefficient and the natural light situation can be adjusted, however only in a limited range. [1, p.190, 220] A new material (Nowoflon ET 6235 Z-IR) uses a solar-infra-red absorbing effect. Solar infra-red rays which are to a large extent responsible for heating up the building are absorbed by the film (which however leads to an increased secondary heat-transfer in the long-wave IR). [3] Another new material uses the passive daytime radiative cooling with a cooling power of up to 93 W/m² through the atmospheric window in the spectral range to cool down the interior space even during the day. [4] This material however has not been tested under real-live conditions so far (weathering, increasing absorption due to dirt/dust-accumulation or soiling, UV-stability).

The presented new shading approach is inspired by the widely used architectural idea of the shed roof (saw-tooth roof). By using this geometrical idea with foils on a much smaller scale the direct sunlight is blocked off, whereas the steeper surface is oriented away from the direct solar radiation and allows diffuse sunlight in with a high visual transmission of about 92% (transparent ETFE foil). The saw-tooth structure is downsized to a millimetre scale. This requires a geometric modification of the foil. The foil will not only be printed with a pattern, but also additionally spatially transformed, so that the printing pattern can be adjusted considering the sun´s position and the direct sunlight radiation. The spatial transformation with the consideration of the printing patterns is relevant for the reduction of the direct radiation inside the building to a minimum depending on the location. This improves the thermal comfort, saves cooling energy and achieves a largely glare- and shadow- free light situation with sufficient natural light.

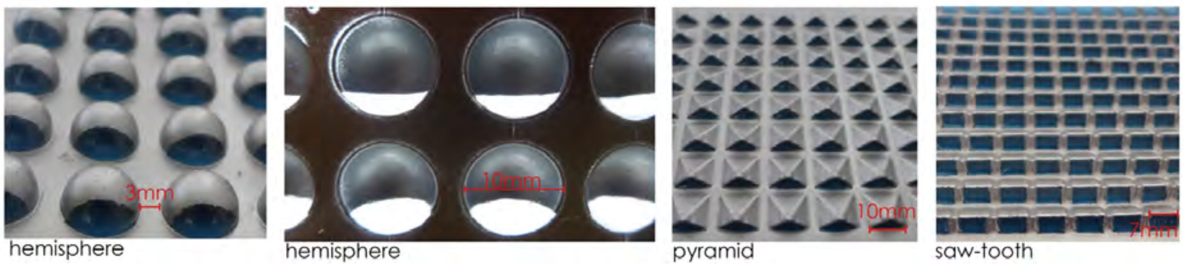

Figure 1. Samples of the new foil type in lab-scale

This allows for new creative- and application-oriented use of space in different climate regions, because natural daylight is extremely important for the visual comfort in covered areas (e.g. shopping malls). A comparable application of the shed roof idea has been followed up before which had involved one of the authors, but on the large scale of membrane cushions: For the roof and façades of the shopping mall "Dolce Vita Tejo" close to Lisbon, membrane cushions with the dimension of 10m x 10m and with partly double printed ETFE foils have been realized on an area of more than 40.000 m^2. They show the idea of a north light shed roof within the geometry of the cushions. In this project, membrane structures (ETFE foils) were mainly used, because allow for a lighter and therefore less expensive substructure compared to a conventional overhead glazing [1, p.256ff].

This study focuses on the summer case (cooling). To calculate the cooling load and to assess the thermal and visual comfort, dynamic simulation software TRNSYS 17.02 and DIVA 3.0 are used. The reduction of the solar gains by the spatial transformation foils in the summer case and the resulting cooling energy saving potential with sufficient natural light will be investigated.

Building integration (architectural qualities)

The new spatially transformed foil can be both applied for roof- and façade areas, thereby the considered printing patterns and the correct orientation of the installation is an important factor. Membrane cushions have at least 2 layers of foils which are stabilized by air at a low overpressure of about 200 - 800 Pascal [2-8 mbar] depending on size, geometry and external loads (wind, snow). Additional internal layers can be installed to get more air cavities. A typical heat transmission coefficient (U-value) for a one layer construction is about 7.3 W/m²K, for a two layer construction about 3.1 W/m²K and for a three layer construction about 2.1 W/m²K, also depending on heat flow direction and orientation (up/down resp. horiz./vert.).[1, p.216]

In a first step, we investigate the new spatially transformed applied as a middle layer of a cushion. The benefits are: flat application, no complex cutting patterns, very low mechanical stresses over the foil by the pressure equalization, no environmental influences (weathering, soiling), more flexibility with regard to orientation towards the sun.

Form optimization

The following simulations and form optimizations are based on the climate data by the German Meteorological Service (DWD) of the climate region of Stuttgart, Germany (latitude: 49°, longitude: 9°). External influences for the form optimization are the position of the sun by the zenith- and azimuth angle, ambient temperature [°C] and the intensity of the direct and diffuse irradiation [kWh/m²a] on the surface. Over the year, a horizontal surface has the highest irradiation, which falls by a steeper angle of the surface. The same applies to diffuse and direct irradiation. This leads to high losses by conventional sun protections regarding solar gains and natural daylight for the winter case and overheating problems in summer. Considering the moderate to hot climate (T_{amb} > 20 °C) with the corresponding high irradiation, results to a period where sun protection is unavoidable in the time from May 19th to Sept. 7th. The optimum solution we found is a geometry with an angle for the south surface of 23° and an angle of 16° for the south-east and south-west surface. The north side has an optimal slope of 65° (highest sun position). Therefore a large amount of diffuse irradiation and natural light enters the building, but no direct irradiation. From an economical point of view, this means that huge manufacturing costs for an optimal location-specific spatially transformed geometry is necessary. Therefore, we investigated the idea of using a fixed geometry which can be combined with adopted printing patterns according to the project's needs. This lead to a hemisphere geometry.

To achieve an optimally coordinated printing pattern, the geometry is investigated on the direct irradiation. Figure 2 shows as an example of a hemisphere geometry the different printing patterns. For a whole year the ideal printed part is found to be about 73% and for the relevant period (May 19th to Sept. 7th) about 57%. These simulations were executed with the software RHINO and the Plugin GRASSHOPPER with the add-on LADYBUG. We considered a gap between the hemispheres to allow for the mechanical stress distribution within the ETFE foil that is needed for the application as a middle layer in a cushion.

Figure 2. Hemisphere geometry a) printing part of one year b) printing part with time limit

Simulation Method

The following describes the method to achieve the desired effect regarding to the direction-selective printing patterns. Variants are defined and compared in the simulation software TRNSYS and DIVA.

Physical properties

The basis of numerous simulation is the exact determination of physical properties for the material characteristics. Therefore, the Bavarian Center for Applied Energy Research (ZAE Bayern) has provided spectral data of the clear ETFE-foil with a thickness of 200 µm measured according to DIN EN 410. The background of the measurement data is the analysis of angle dependent data with Optics 6.0 and Window 7.4. The calculated parameters (Fresnel formula) from the measurement data is written in a DOE-2-report. Table 1 shows some important parameters which were used for the TRNSYS simulations.

For the daylight simulation with DIVA 3.0 (based on the software tool "Radiance") calculated diffuse reflection and diffuse transmission coefficients are used for the input file, see Table 2. Assumptions were made for the calculation of the printed ETFE foil with regard to the reflectance (55%), transmittance (5%) and the absorption coefficient (40%).

Table 1. Simulation parameters for TRNSYS

WinID-Lib (TRNSYS) *Description*	g-Value *[-]*	T-sol *[-]*	Rf-sol *[-]*	T-vis *[-]*	Data generated *[software]*
ETFE - clear	0.933	0.93	0.061	0.923	OPTIC/WINDOW
ETFE - printed	0.201	0.074	0.58	0.057	OPTIC/WINDOW

Table 2. Simulation parameters for Radiance

Window (RADIANCE) *Description*	color *red/green/blue*	specularity *[-]*	roughness *[-]*	transmission *[-]*	transmitted *specularity*
ETFE - clear	0.98	0.08	0.00	0.99	0.98
ETFE - printed	0.44	0.29	0.00	0.16	0.40

Thermal simulation (3D Model for the building simulation)

A fictitious 3D- Building model which was built in SketchUp 8 with the Plugin Trnsys3d that represents an atrium with a 3-layer membrane cushion in the roof area, cp. Figure 3. The dimensions of the abstract building are 20 meters x 20 meters and 10 meters height, with a total volume of 4000m³. It consists of 3 radiation zones and a total of 7 airnodes. Zones I to V are coupled with a defined air mass transfer. Thereby zone I is at the bottom and zone V is directly below the roof. The air mass is transported from one zone to the next zone on top with a fix air change of 2/h to the upper zone. It is assumed that 10% of the air mass of one zone is transported downwards due to convection effects. The roof area is divided into 24 horizontal fields which represent the hemisphere geometry abstractly, because TRNSYS can not directly handle curvature. For the same reason the curvature of the membrane cushion is not depicted as well. The 3 - layer membrane cushion is modelled with a space of 0.50 m between each foil and a total volume of 200 m². The boundary temperature of the atrium´s walls is defined with a constant temperature of 20°C and the boundary ground temperature with constant 15°C. Additionally the atrium is surrounded with a shading group (purple colour) to block solar irradiation.

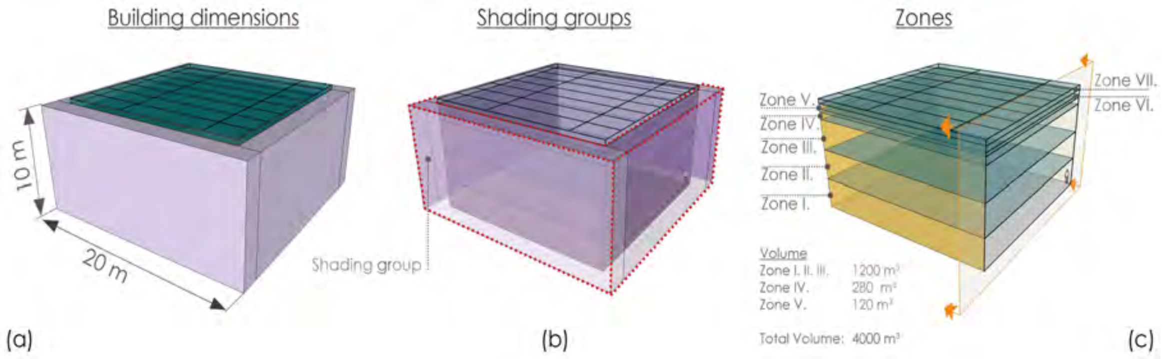

Figure 3. 3D – Model for the building simulation: a) building dimension b) shading groups c) zones

Dummy Zone

A special requirement for the simulations is to represent the small-scale structures. Unfortunately, it is not possible to simulate the geometry in a 1:1 scale with TRNSYS. Therefore, a "dummy zone" with a higher scale factor of 10^3 is created. However, due to the complex form of the hemisphere geometry, the hemisphere is split into 24 single surfaces, cp. Figure 4b. The essential geometry is located in the middle around 8 identical geometries (Figure 4a). This is necessary to get the shading factor for one geometry to each other. The generated *.shm file (Figure 4c = one surface) will then be transferred to the external membrane layer of the multi-zone building.

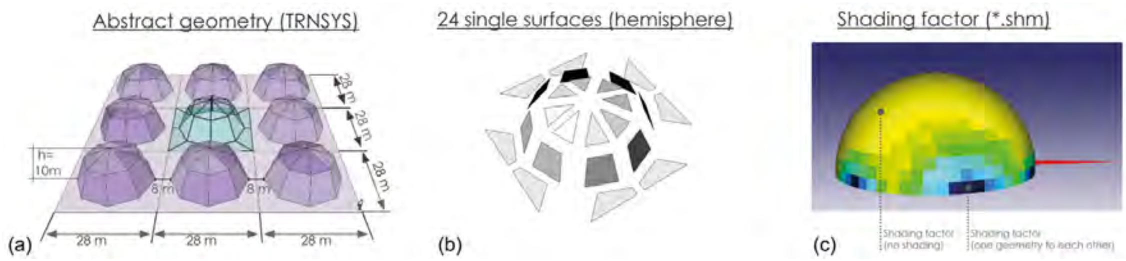

Figure 4. Dummy zone: a) abstract geometry b) single surfaces c) shading factor

The resulting "dummy zone" in TRNSYS shows additional information about the orientation, the shading factors and view factors to the sky for the individual surfaces: (slope: 70 deg. - 0.68, slope: 25 deg. - 0.95, slope: 0 deg. – 1.0). The printed part to block direct radiation is set to 66% and the clear part to get diffuse radiation into the atrium is defined as 44%.

Results and Discussion

Thermal Comfort

The thermal comfort is evaluated by the operative temperature (human thermal comfort), which is a useful parameter to compare simulation results, because the boundary conditions are considered to be the air temperature and the radiance temperatures of the surfaces inside the building. Thereby, for the rating of the variants the number of hours above the operative temperature of 26°C inside the atrium (without a cooling system) is analysed. For the evaluation of the thermal comfort it is assumed that the atrium is used Monday to Friday from 8 am to 7 pm with nobody present at weekends. Figure 5 shows the relative simulation results for the different geometries and zones (I to V) over one year.

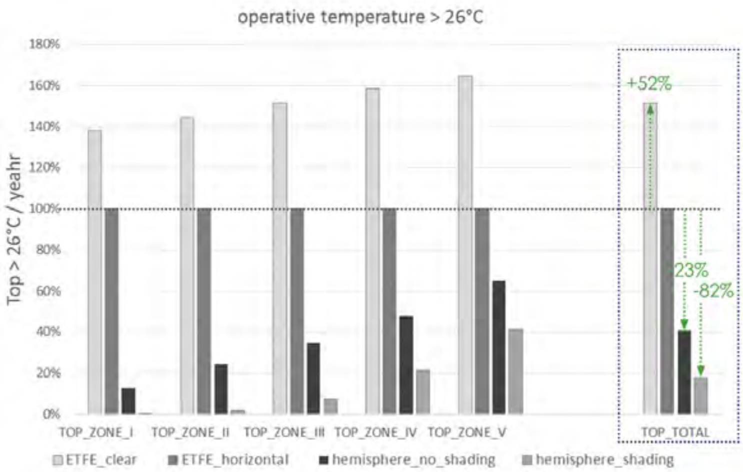

Figure 5. Thermal comfort (operative temperature > 26°C)

Variant "ETFE_clear" is the worst option for the thermal comfort in the summer case, because it consists of a membrane cushion with simple clear ETFE foils in all three layers. The variant "ETFE_horizontal" is defined as the related reference (100%). It has a typical printing ratio of 66% without any spatial transformations. The improvement of the thermal comfort by the spatially transformed foil reaches up to 82 %. Two explicit variants of the spatially transformed foils were calculated. One is calculated without the own shading factor and the other one with the own shading factor (*.shm) to show this important effect. With the own shading factor in variant "hemisphere_shading" the improvement compared to variant "hemisphere_no_shading" reaches up to 22 % for the summer case.

Cooling and heating loads

The cooling time period for the summer case is from May 19th to Sept. 7th. It is necessary to cool down the atrium to 26°C within this period. The energy demand for heating up to 22°C during the day and 16,5°C during the night is calculated for the winter case (Sept. 8th to May 18th). We considered no more internal gains inside the atrium, because this has no significant influence on the rating. All results are based on simulation time steps of 0.25 hour.

The relative results for the energy loads are showed in Figure 6 for the heating and cooling case. Again, the conventional variant "ETFE_horizontal" is the reference variant to compare the energy loads (100%). By changing the upper layer with the spatially transformed foil compared it is possible to reduce the cooling load by about 69% compared to the horizontal printed ETFE foil. Without the consideration of the own shading factor "hemisphere_no_shading" the cooling load is reduced by about 52% compared to the reference variant. The heating energy demand in the winter case increases, when the spatially transformed foil is used. In variant "hemisphere_shading" the increase of the heating energy demand is about 11% and in variant "hemisphere_no_shading" about 5%.

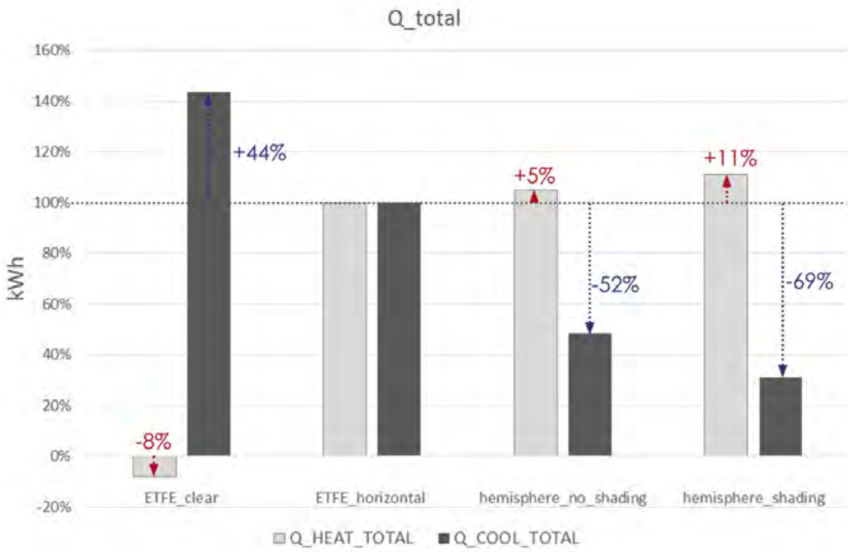

Figure 6. Heating loads (light grey) and cooling loads (dark grey) [kWh]

Daylight simulation

The visual comfort is as important as the thermal comfort, especially for lounge areas or the previous example for atriums. Due to the high transparency of the ETFE foils (τ_{vis} 92% @ 200µm) the risk of glare effects by too high luminance inside the building is extremely high [5]. Moreover unpleasant shadow effects could arise.

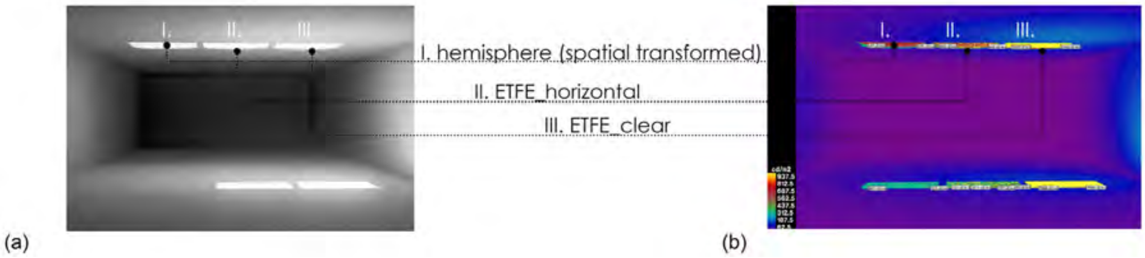

Figure 7. Daylight simulation a) shadowing b) false colour

Figure 7 shows an example of a daylight simulation for June 21st at 12:00 o´clock at noon (highest sun position) with a clear sky and direct irradiation. Illustrated is a 3 –layer membrane cushion. The dimensions are 0.5 meters x 1.0 meters. Three different variants are investigated of the glare- and shadow free situation. The printing part in variant I. (spatially transformed, hemisphere r=10mm) and variant II. (horizontal printing without spatial transformation) amounts to 66%, variant III is not printed (clear ETFE foil).

Figure 7 shows, that with variant I (≈ 300 cd/m²) a pleasant luminance inside the building plus a sufficient reduction of direct sunlight for a pleasant workplace (DIN EN 12464) could be achieved. Variant II (≈ 1000 cd/m²) and variant III (≈ 8000 cd/m²) indicate a too high luminance on the workplace.

Further daylight simulations (daylight utilization) will be investigated in another currently unpublished paper.

Conclusion and Outlook

The main aim of the present study was to describe the potential of the new spatially transformed ETFE foil with regard to the improvement of thermal comfort, energy consumption and daylight quality. It was difficult to model and simulate the extremely small scale of the structure with consideration of the orientation, own shading factor and the optimally coordinated printing pattern. Compared to a conventional ETFE foil (flat printing), the thermal comfort of a spatially transformed foil was found to improve by about 82%. However, the results have to be validated by measurements (transmission, reflection, g-values for different angles) as soon as we have larger material samples. The informative value of the simulations results alone is limited as a lot of factors can lead to different findings. The high improvement comes from the blocking of direct sunlight. It is expected to save up to 69% cooling energy compared to a horizontal printed foil. In the winter case, as a consequence of the reduction of solar gains, the heating energy demand increases about 11%. In order to make a more precise estimation, a site-specific simulation should be carried out. The natural daylight results shows that a pleasant workplace with about 300 cd/m² could be achieved in the summer case.

The simulation results can be validated with these measurement data. At the end and if the new spatially transformed ETFE foil can also be put to production on a larger scale, it might allow for significantly improved solar protection of membrane cushion applications.

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Design to Thrive

The impact of building height and construction on life cycle analysis calculations

Asif Din[1] and Luisa Brotas[2]

[1] The Sir John Cass School Art, Architecture and Design, London Metropolitan university, London. UK, aud0034@my.londonmet.ac.uk;
[2] The Sir John Cass School Art, Architecture and Design, London Metropolitan university, London. UK, l.brotas@londonmet.ac.uk

Abstract: There is no fixed method to analyse the carbon impact of a building. The most comprehensive guidance given in BS:EN 15978 (BSi, 2011) but provides a poor understanding for designers on how building components make up the Green House Gas impact of buildings. This study quantifies different construction materials within a building showing their significance at differing Life Cycle stages in relation to the design lifespan. The study is conducted through 3 and 6 storey timber, steel, concrete buildings covering differing foundation typologies. An existing software package ATHENA and an elemental bottom up approach is used to compare relative impacts. Apartment floor areas used in UK regulations create large variations in the assessment of Life Cycle impacts which do not include communal areas which requires a whole building approach. There are not large variances in the overall Life Cycle between differing construction types with concrete reducing replacement factors, steel with high recyclability potential in later Life Cycle stages and timber sequestering carbon in early stages of the building Life Cycle. Elementally foundations, upper floors and facade materials have the most influence and should be considered carefully at an early design stage.

Keywords: LCA, Apartment buildings, Building Lifespan, Future Carbon Use

Introduction

When considering the life span of a building it is important to promote the architect's understanding of various design implications and their impact on lifetime Green House Gas (GHG). As buildings are made up of hundreds of products whose interaction is not straight forward, it is unpractical for designers to understand their design choices, to conduct an extensive assessment of materials early in the design process. Full Life Cycle (LC) quantification in previous studies are often inconsistent on the LC stages and measurement parameters used, despite many using BS:EN 15978 (BSi, 2011a), a modular framework which is also adopted in this study. Additional problems include the lack of a standardised methodology in quantifying the impact of apartments units within larger structures. Currently in UK regulatory standards as operational carbon is determined by internal floor space only (Building Regulations, 2013). Measurements do not accurately quantify materials for a building in a LC study and exclude common areas.

The use of building materials needs to be considered across a range of LC stages otherwise an incorrect assumption may be made, for instance where an unrobust material must be replaced several times over the building's life. Considering the full LC impacts the operational carbon is important to determine when overheating is likely to occur. This is conducted using CIBSE TM52 (CIBSE, 2013) methodology in naturally ventilated buildings, detailed in a previous study (Din and Brotas, 2016) that used weather files from Eames et al (2012) to produce a dynamic model using future climate data to account for different constructions. The study presented the likely date for active cooling to be adopted and determined the subsequent GHG impact.

Aim

This study assesses typical apartment buildings using ATHENA (2017) software against a bottom up methodology utilising comprehensive Life Cycle stages, where practical, to determine the LC stages of importance in a GHG calculation of a building. The GHG of differing constructions types demonstrates the main features that influence the whole Life Carbon solution, for a given building life span.

Background

Menzies et al (2013) identified a range of LC free tools, the one that was most closely aligned to the construction process was ATHENA (2017) Impact Estimator for Buildings, a US based software which covers a range of LC stages of a building life span.

Within previous academic literature a range of life spans for dwellings were adopted (Chastas et al, 2016) but 60 years is most commonly used by the industry. This is the basis of BRE certification (Anderson et al, 2009), and 100 years is used in PAS 2050:2011 (BSi,2011b) for products. The apartment buildings in this study use these life spans with associated replacement factors along with the influences on operational GHG.

Previous studies have quantified the Embodied Carbon of foundations (Sandanayake et al 2016) in isolation but do not deal with the superstructure or other systems that impact LC values. An holistic picture is required so that design dependencies can be understood. Most foundation types require concrete (which has a high GHG impact) with pad, strip and pile foundation typologies used in this study dependant on the height and construction weight of the apartment building considered. These archetypes are based on a good ground bearing conditions rather than real life solutions where physical surveys and investigations can influence the final structural design.

Environmental Product Declarations (EPD) (BSi, 2012) are used as the GHG dataset for construction materials directly from manufacturers. In particular EPDs account for sequestration (Wood for Good, 2014) which highly influences timber construction calculations. As a result, this paper investigates the influence of sequestration over differing LC stages. In contrast, heavyweight materials (CIBSE, 2016) have the advantage of storing heat which delays the installation of air conditioning thus minimising operational GHG.

Some LC stages are practical to quantify whilst others are not, due to lack of information available and their impact on the overall LC value is discussed in the paper.

Product stage			Construction		Use stage							End of life			
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4
raw material suppy	Transport	Manufacturing	Transport	Construction Installation Process	Use	Maintenance	Repair	Replacement	Refurbishment	Operational Energy	Operational Water	Deconstruction Demolition	Transport	Waste processing	Disposal

Figure 1. Stages within BS:EN 15978 (BSi, 2011) by author.

Three and 6 storey apartment buildings are evaluated with a core serving two apartments per floor, a typical arrangement for many multi occupancy buildings. In the case of the 6 storey solution a lift is added to show its influence the on LC calculation. These solutions comply with the UK building regulations although the 6 storey timber building would not due to a lack of redundancy required in disproportionate collapse in the current regulations, it is presented in this study for comparison purposes. A number of duplications in measurements occur and are discussed as part of the results.

Methodology

Each individual apartment has a floor plan layout is similar to those dynamically modelled in a previous study (Din and Brotas, 2016). The Gross Internal Floor Area (GIFA) remains constant but the Gross External Floor Area (GEFA) changes according to the construction used. The U values of the dwelling envelope is similar in each case by compensating the thickness of the insulation layers. The dwellings are organised in a 3 and 6 storey blocks and individually named to assess the importance of their position within the block. A floor to ceiling height of 2.5m is used, in line with PassivHaus Planning Package (PHPP) default calculations.

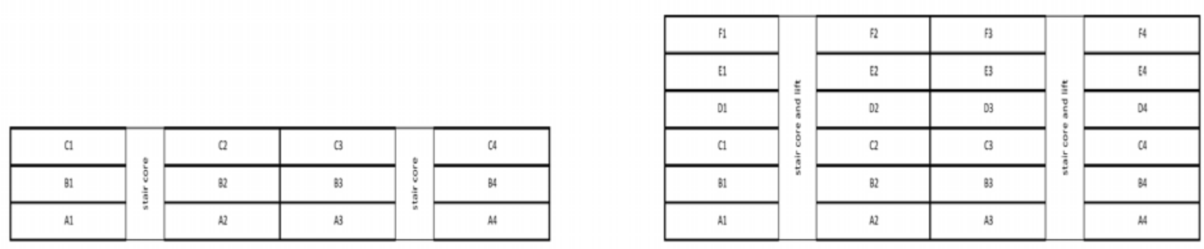

Figure 2. Dwelling nomenclature used to identify apartments within the blocks modelled

The 3 structural types used reflect the majority of the UK apartment market. Each typology influences the construction of other elements used within the building and are summarised in Table 1.

Table 1. Construction specification of each model.

Structure	Timber	Steel	Concrete
stairs	wood	sheet steel	precast concrete
lift core	cement board	cement board	concrete block
foundation			
3st	450 concrete strip	concrete pad	600 concrete strip
6st	600 concrete strip	precast pile	precast pile
ground floor	concrete slab	concrete slab	concrete slab
party floor	timber I joists	steel tray with screed infill	hollowcore
ext wall	timber, insulation, sw boards	met sec, insulation, cement board	block, insulation, block
internal wall	timber	met sec	timber
windows	double glazed timber	double glazed timber	double glazed timber

It should be noted that all timber is Forest Stewardship Council (FSC) certified and the concrete used is 50% cement replacement in line with current industry norms (with reinforcement added according to current structural regulations) and metals with a 70% recycled content. The ATHENA software is used for the 3 storey buildings of differing structures over 60 years. All the input values quantified in both the software and the bottom up analysis are identical to ensure consistency. The basis of the elemental calculation is as follows:

LC Stages A1-A3 the GHG is quantified using EPDs from manufacturers. Taking the weight of elements stage A4 is established by using 30km road transport in 10 tonne truck loads. In addition, timber is sourced from Poland (with associated road transport) and steel from China (a combination of container ship and road transport) these parameters avoid the investigation of individual supply chains resulting in a unique LC analysis rather than an archetypal one.

Stage A5 is approximated as 6 months of a digger on site for foundations or a piling rig for 3 months. Other equipment used includes 6 months for a forklift and 6 months of 10 power tools with an additional 6 months of power tools for a concrete structure with a cement mixer for 6 months. Construction timescales and equipment used are doubled for 6 storey structures apart from the piling rig. These approximations are based on observations, experience and construction site records.

Stages B1 to B3 are not included in this study as these would require observed facility management records and site assessments. Stage B4 is used instead with replacement rates based on Williams et al (2012). Within this stage buildability (replacing dependant elements), disposal, recyclability and deconstruction of the replaced material is considered based on a smaller LC study within this module. Stage B6 is based on a Din and Brotas (2016) energy use under future climates, by assessing the reduction in heating and the increase in overheating periods to estimate the date of adoption of active cooling systems and the associated GHG usage. Hot water and appliance loads have been accounted for from a PHPP calculation for an individual flat. In addition, an annual reduction of 2% in grid carbon is calculated as an extrapolation of the last 10 years UK electrical grid figures (DEFRA, 2017) to account for future grid decarbonisation through the adoption of low carbon generation sources. Stage B7 is ignored as this has little GHG impact but has a greater weighting within other LC indicators.

Stage C1 deconstruction, is established as 3 months for a concrete/steel building and 2 months for a timber building. The basis of the calculation of stage C2 is by mass in a 30km radius to a recycling plant or landfill in the UK. C3 recycling rates are taken from WRAP Net Waste Tool figures (Burton and Freidrich, 2008) by assigning a proportion of the original GHG value dependant on the recyclability of the material. This stage is not calculated from EPDs figures, which give an optimistic end of use scenarios such as waste to energy. C4 is the residual calculated amount land filled with materials classified either as inert or degradable with the associated GHG outcome. D stage of the LC dealing with reuse is ignored as this is beyond the scope of the study boundaries.

Given the detailed data classification outcomes can be presented in various formats. The ranking of the design importance of the findings is discussed.

Results

As ATHENA is an US based software some input parameters available may not be appropriate for other locations. This requires compromises to be made on the location and the associated GHG values for grid carbon (for its internal calculations). In addition operational carbon B6 is not considered by the software. The results are broken down by stage and by material classification in Figure 3. These are for the 3 storey block of the differing construction types over 60 years covering stages A-C of the building LC.

The clear distinction can be made between the different constructions with a penalty for using a timber construction with an increased number of replacement cycles within the building lifetime. Stages A1-A3 predominate the results and may encourage designers to adopt a timber building design for the archetypes explored.

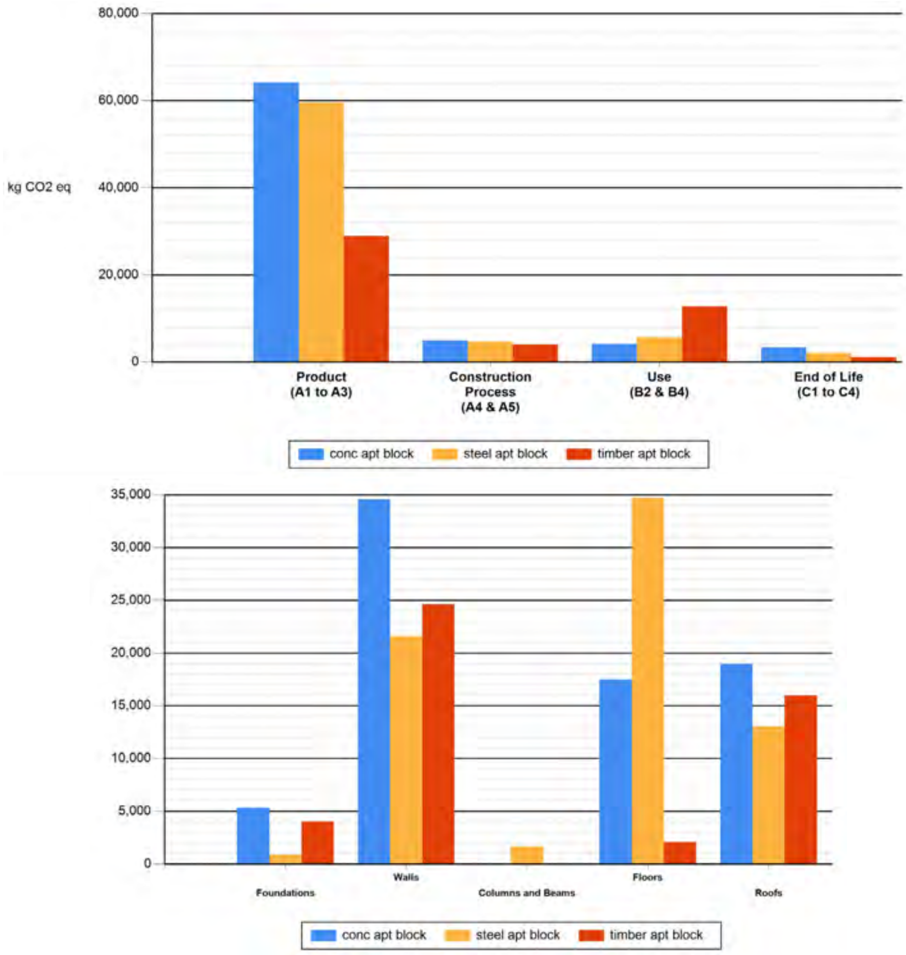

Figure 3. GHG ATHENA breakdown by building component

Foundations play a minor role in the component breakdown in ATHENA with the external walls and floors being the most critical elements within the concept design for the overall building. These distinctions would be proportionally larger for the 6 storey building with unchanging areas of the roof and foundations spread across more of the overall GEFA of the apartments.

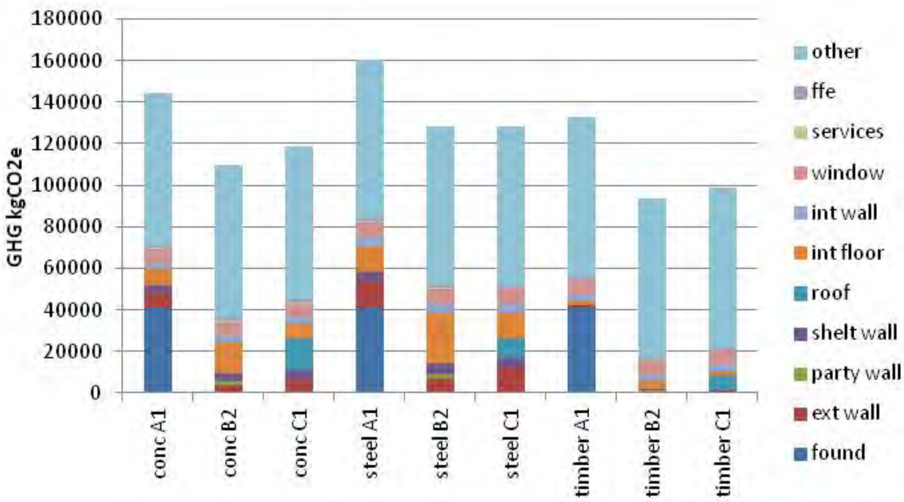

Figure 4. component breakdown by unit location

In Figure 4, the 'other' section includes transportation of materials and the operational carbon of the dwelling which is largely consistent in all units regardless its location in the building due to high insulation levels. Where a dwelling is placed on the ground floor (A1) the foundation causes a significant increase but is replaced by wall and floor influences in upper dwellings following the trend in the ATHENA results. The values given in ATHENA are low in comparison to the building overall when the number in Fig 4 is multiplied for the whole building. 9% of values measured are consistent across all cases which cover elements such as kitchens, bathrooms and services. The dwellings GHG values (excluding other) range from lowest to highest by a factor of 10 between a mid timber B2 apartment and steel A1 ground floor unit.

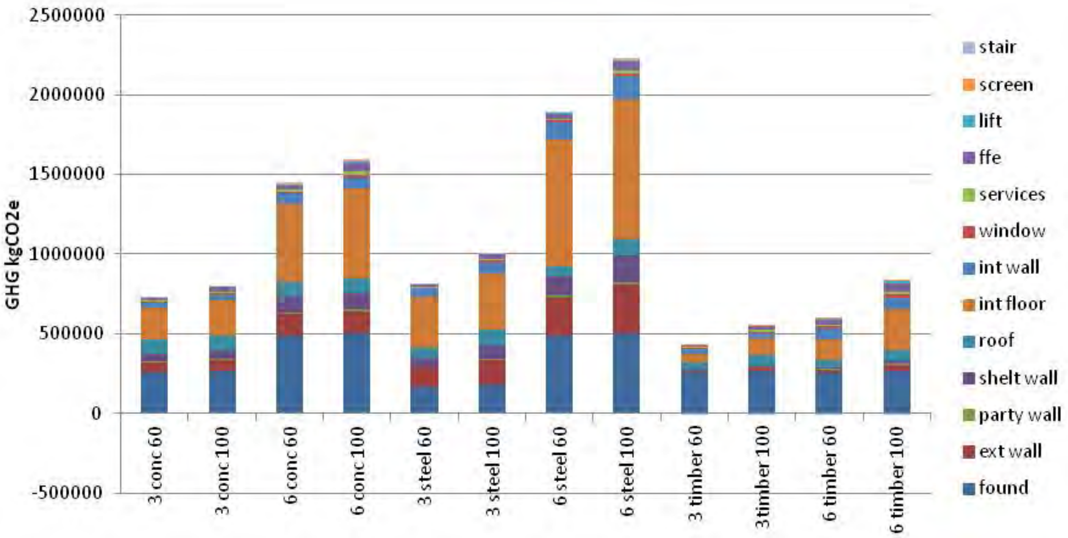

Figure 5. Building type by construction, height and lifespan

Figure 5 shows that the taller the building is, the higher is its proportional LC impact however, this is more than compensated by the amount of dwellings the block contains and its overall GEFA. Foundations (13% in the case of a pad foundation) are a major component second to internal floors (21%), in multi-storey buildings. Roof types vary little between construction typologies and foundations have a single influence on the overall result. The operational B6 and construction A4, A5, C1, C2 values are excluded from the graph due their largely consistent value, which makes up over half of the LC quantification.

The variation in facade materials using timber as a base case, is that a load bearing concrete facade has a factor of 4 times more GHG and a steel lightweight metal section (met sec) wall 6 times higher GHG value across all the LC stages.

Figure 6 shows the impact of all LC stages on each construction typology. The operational B6 stage contributes to 60% of the buildings overall GHG expenditure and shows an area where the designer's decisions can have an important impact. About 30% is in the A1-A3 stage which has the most impact on the environment as this stage typically lasting 1-2 years rather than the longer timeframe of the operational GHG used within stage B of a LC study. Replacement accounts for around 12% of the overall value showing that buildings should be built for longevity rather than demolition (C1) and expending the GHG of stage A of the LC again.

Currently only a small proportion is recovered from buildings at around 5% of the GHG (concrete piling excluded due to difficulty of extraction). Although this is larger for a steel building, due to the full extent of the subsequent supply and international transport chain to a new building product and its proportional mixing with virgin material, has not been assessed in this study, which leads to a lower steel recycling advantage.

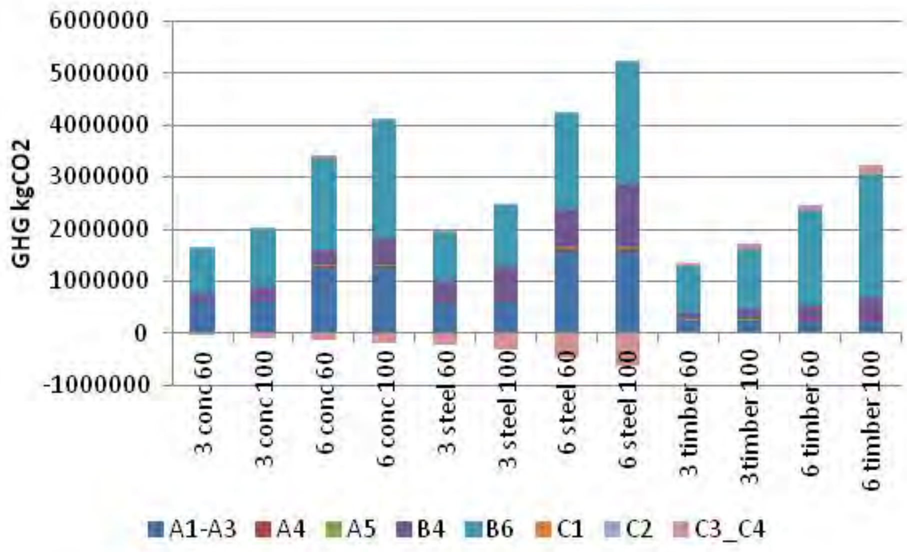

Figure 6. Building breakdown by LC stage

Future Implementation

The transportation in supply chains has been approximated in this study along with the omission of the maintenance and repair of buildings which has the potential to make heavier weight buildings lower in overall GHG impact and compete with the GHG of a timber building. The variation in site carbon is interesting and a further level of detail from site measurements, with indirect carbon through workmen transportation values, may create a better quantification of this stage.

The implementations of stage D and its accounting methodology for the transferable reuse of materials is critical in properly assessing the impact of stage C in a project LC along with the practicality of the proportion of recycling needs. This study shows guidelines can be established when stages outside of traditional 'Cradle to Gate' analysis.

Conclusion

ATHENA has the correct order of magnitude of results for the superstructure of a building but not to its substructure especially when piling is used. There is an overestimate of stage B of the LC compared to in depth studies conducted.

Results show GHG of differing structural materials are inconclusive with other LC stages influencing results significantly. A piled foundation does cause considerable GHG expenditure leading to arguments for taller buildings to expend the GHG of piling across more dwellings. Other aspects such as internal floor construction may be resolved by using a hybrid design approach, differing structural materials and other building construction elements.

The analysis of dwellings within the blocks show a large variation depending on the construction and location but does not lead to useful results when shared services are accounted for. A steel building has the worst GHG impact , as a result of the international transportation distances covered but does gain credits from its recyclability. Timber buildings have the lowest GHG impact but the sequestered carbon is largely released back into the environment at its disposal stage. Buildings should be built for longevity as demonstrated by concrete structures with the proportional increase in GHG being insignificant compared to the life time of building service.

Given the incremental decrease of grid carbon more needs to be done in terms of reducing the amount of operational carbon in buildings. Particular areas of interest are appliance and hot water loads which are not adequately addressed by current regulations or PassivHaus standards. The results do show a framework for a toolkit to show the significance of factors to consider at the design stage even if the results given do not show a distinct construction preference. Results both by life cycle stage and material need to be considered in parallel within the design process.

Acknowledgements

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Responsive Plant-inspired skins: A review

Yomna ElGhazi[1, 2], Neveen Hamza[1] and Martyn Dade-Robertson[1]

[1] School of Architecture, Planning and Landscape, Newcastle University, Newcastle upon Tyne, United Kingdom;
[2] Department of Architecture and Environmental Design, Arab Academy for Science, Technology & Maritime Transport, Cairo, Egypt.

Abstract: Sun-shading plant-inspired skins can use plant actuation principles to develop reversible motions. This paper describe the intersection between plant actuation principles, their morphology and low energy strategies, to propose potential mechanisms in responsive dynamic shading skins. This paper will investigate non-autonomous reversible plant movements to develop elastic kinetic solar screens. New approaches to soft mechanics have found inspiration in plant movements applied to pliable structures in architecture. Interestingly, global flexibility is often achieved through the adaptive behaviour of plants that change their morphological features by acting as living hinges and allowing for elastic deformations. These motion patterns are found in nastic structures which are very promising as natural actuators. By studying how plant species take advantage of mechanical, compositional and structural gradients to perform mobility with minimal energy use, it is possible to learn how to integrate these properties into the design of kinetic shading solar screens. The focus of this review is to understand soft mechanics approaches and their applications for responsive shading skins. A critical review of the current progress in mechanical properties and actuation principles of nastic plant movements is illustrated.

Keywords: Responsive skins, Plant movements, Biomimetics, Deployable structures, Actuation

Introduction

The urgent demand for more energy-efficient and sustainable architecture is leading to a growing interest in kinetic skins that can adapt to changing environmental conditions (Fiorito *et al.*, 2016). The term 'Kinetic skins' has come to be used to refer to building envelopes capable of configuration changes due to their geometrical, material and mechanical properties (Adrover, 2015). Recent literature shows that most environmental kinetic facades are based on mechanically operated systems. A mechanical system, such as Al Bahr Towers in Abu Dhabi, has the disadvantage that it is complex to build, difficult to maintain and require high energy consumption (Reichert et al., 2015). Lately, more recent attention has focused on two approaches that have the potential to simplify the mechanical designs utilized in kinetic skins, Biomimicry and Smart materials.

Plant tissues have the capability to adapt to constantly changing environmental conditions even when their cells are dead. This is achieved through iterative feedback loops, which sense, record, inform and instruct the fibre composite to alter their current configuration towards an optimized one (Mingallon and Ramaswamy, 2012). By studying how plant species take advantage of mechanical, compositional and structural gradients to perform mobility with minimal energy use, it is possible to learn how to integrate these properties into the design of kinetic shading solar screens.

Moreover, the investigation of new responsive smart materials could simplify mechanical actuation (Reichert et al., 2015). Materials with embedded actuation can alter their morphology under external stimulation and adapt autonomously to their respective environmental conditions (Schaeffer and Vogt, 2010; Reichert et al., 2015). Smart materials have permanently reversible properties which can be triggered by external stimulus such as temperature (Schaeffer and Vogt, 2010). For example, Shape memory alloys have the potential to act as a servo-actuators to design low-tech responsive skins. The activation temperatures of Embedded Shape Memory Alloys can be achieved in hot arid climates through direct solar contact and can be applied for responsive solar shading skin. This paper concentrates on the mechanical, compositional and structural constraints which enable plants to actuate their organs, summarizing current knowledge in how plants generate movement. It focuses on reversible plant movements with a view to the development of elastic kinetic solar screen.

Biomimetic Approach for efficient movement

Biomimicry is imitation of nature to design objects and systems help in solve human problems. Some designers and researchers argues that nature is the best, most influencial and the guaranteed source of innovation. Plants can be a promising inspiration source to learn soft mechanics (Schleicher et al., 2015). Suitable analogues can be developed into responsive motions production that could meet design as well as sustainability demands. Plants have evolved the capability to respond to a wide range of signals and efficiently adapt to changing environmental conditions. They perform mobility with minimal energy use, due to the fibre elasticity composition and integration of sensing and actuating capabilities into their system (Fiorito et al., 2016). In particular, the leaves and pedals bending and folding mechanisms demonstrate how the number of mechanical parts can be reduced by making use of flexible and elastic material properties and allow reversible deformations (Poppinga *et al.*, 2010; Schleicher *et al.*, 2015).

For biologists, the classification of plant movements is an important aspect to understand how plants develop morphogenesis (Boudaoud, 2010), and specially how they respond to environmental stimuli. Plant biologists distinguish between nastic and tropic movements. The movement in nastic responses is independent of the spatial direction of a stimulus, whereas tropic movements are influenced by its direction (Burgert and Fratzl, 2009; Schleicher, 2016)**.** Generally, Nastic movements occur due to the swelling and shrinking of motor cells and result in reversible movements that could be of high interest in responsive skin applications (Ueda and Nakamura, 2006; Poppinga *et al.*, 2010). In order to understand how plants' movements develop in general, they will be analysed through different applications in mechanical, compositional and structural systems.

Actuation mechanisms in Plant Movements

Numerous studies have attempted to classify plant movements. Poppinga et al. (2010) developed wide-ranged matrix focused on actuation systems found in active or passive nastic plant movements in response of environmental stimuli. The study distinguished between autonomous and non-autonomous movements as well as the active and passive. Non-autonomous movements are mostly reversible deformations caused by a release of stored elastic energy in pre-stressed structures or are initiated by external mechanical forces.

Similarly, (Schleicher, 2016) distinguished between frequently encountered drivers like external loads, growth processes, hydraulic mechanisms, and elastic instabilities.

Accordingly, a more detailed structure of nastic non-autonomous reversible movements is given as shown in figure 1. Reversible Plant movements can be actuated either hydraulically in active way by turgor changes, or in passive way by hygroscopic swelling and shrinking. Other mechanisms use the release of stored elastic energy after an external trigger or by direct application of mechanical forces. The next section will discuss the actuation mechanisms derived by external loads, hydraulic mechanisms, and elastic instabilities.

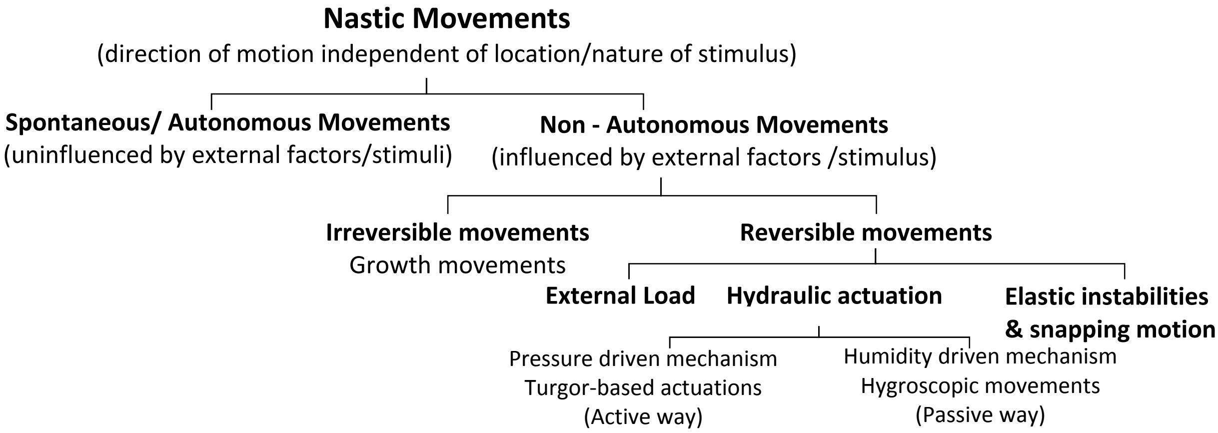


Figure 1. Classification of nastic plant movements.

External loads

The motion of plants can be a response to direct application of mechanical forces. This movement follows an external influencing factor passively rather than being driven by the plant itself. Different loads can act on a plant, such as flowing water, wind gusts, contact with pollinating insects, or attacks of natural predators. According to the plant's composition, an outer drive can either cause an immediate deformation or be diverted to trigger secondary transformation processes (Schleicher, 2016). For example, the movement of the Bird-of-paradise due to the pollination mechanism is triggered by a locally applied load at a specific point as shown in figure 2 (c).

Hydraulic mechanisms

Hydraulic mechanisms in plant movements can be actuated either actively by turgor changes that lead to reversible movement or passively by hygroscopic swelling and shrinking. *Osmotic actuation:* Osmotic actuation is a ubiquitous plant-inspired actuation strategy that has a very low power consumption but is capable of generating effective movements in a wide variety of environmental conditions (Sinibaldi *et al.*, 2014). Living plant cell can generate an internal hydrostatic pressure (turgor pressure) by maintaining an osmotic gradient between its cytoplasm and ambient environment (Li and Wang, 2016). Variations in turgor pressure enable plants to perform volumetric changes and rapid movements (Burgert and Fratzl, 2009; Schleicher, 2016).The pressure driven, water based actuation mechanism in plants is closely related to the hydraulic and pneumatic actuators that are attractive for morphing applications in adaptive structures (Li and Wang, 2016). For example, Mimosa pudica exhibits a rapid, defensive response to external stimuli, closing its leaves and bending its pulvinus. Motor cells, divided into flexor and extensor cells on the ventral and dorsal side of the leaf as shown in figure 2 (a), respectively, regulate the volume and shape according to their relative turgor pressure (Guo *et al.*, 2015).

Hygroscopic shrinking or swelling mechanism: Other than the pressure driven mechanism, plants also exploit a humidity driven mechanism to achieve shape change and actuation. Plant cell walls are composed of a hydrophilic material, so will shrink in volume due to evaporation when they are exposed to dry atmosphere. This process can occur in both living cells and dead cells in the sclerenchyma tissues (Li and Wang, 2016). For example, a change in relative humidity causes a closed, tightly packed Pine cone to open gradually. The mechanism relies on the bilayered structure, the active outer layer of tissue, closely packed long parallel thick-walled cells respond by expanding longitudinally when exposed to humidity and shrinking when dried, while the inner passive layer does not respond as strongly as shown in figure 2 (b) (Reyssat and Mahadevan, 2009). But to be consistent with the scope of this review, this mechanism is only applicable in humid climates.

Elastic instabilities and snapping motion

Elastic instabilities and snap-buckling effects are methods for translating small stimuli into large and amplified movements. Snap-buckling effects speed up movements beyond the limits imposed by simple hydraulic mechanisms. These elastic instabilities are special mechanical failure modes characterized by a sudden deformation of a structural element withdrawing from high tensile or compressive stresses by deflecting into a less strained but geometrically deformed state. In particular carnivorous plants like the Venus Flytrap seem to have mastered that technique (Schleicher, 2016). Interestingly, a kind of "memory" appears to be involved in the leaf closure (Ueda and Nakamura, 2006). The main source of the fast closure is the bistable, doubly curved structure of the leaves, which snap-buckle to reverse their Gaussian curvature upon closing as shown in figure 2 (d) (Guo *et al.*, 2015).

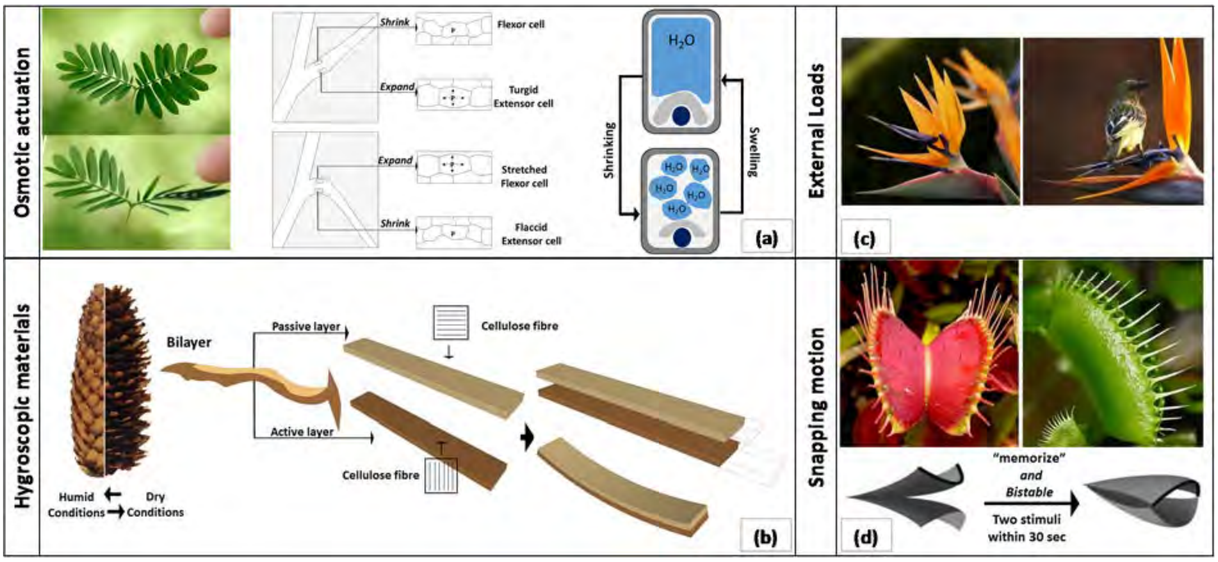


Figure 2. Reversible movements in the plant kingdom.

Compositional features

Plants have also evolved to strategically combine various physiological features with different actuation mechanisms to achieve sophisticated movements (Li and Wang, 2016). Material self-organization is a processes present in the formation and adaptation of biological tissues. They are responsible of the resultant high performance, found in natural fibre composites, to deal with unprecedented environmental conditions (Mingallon and Ramaswamy, 2012). They have the ability to create gradients of tissue, cell or cell wall properties to create actuator-type "smart" materials. The organ deformation is controlled at various levels of tissue hierarchy as shown in Figure 3, which are: Geometrical tissue organization at the micro-level, and Cell size, density and Cell wall polymer composition at the macro-level as shown in Figure 4 (Burgert and Fratzl, 2009). The composition and the geometry of cellular patterns influence the complexity of the actuation system, the folding directions and the reversibility of the system.

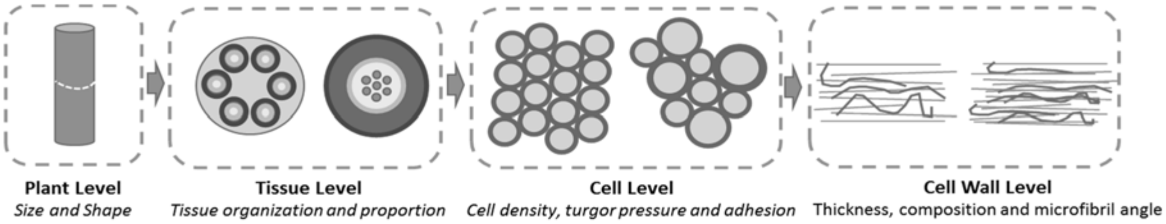


Figure 3. Hierarchy of mechanical parameters influencing plant movements.

Cellular organization (micro-level)

Plant materials are made up of plant tissues, either simple tissues, or complex tissues, each with their own structure (Gibson, 2012). Plant tissues are essentially close-walled cellular solids, which are well known for providing better stiffness and strength to density ratios as compared to their constituent solid materials. Cellular organization could also facilitate movements (Li and Wang, 2016). The cellular structure of plants varies, from the largely honeycomb-like cells of wood to closed-cell, liquid-filled foam-like thin-walled parenchyma cells and to composites of these two cellular structures, as in arborescent palm stems. Honeycombs have prismatic cells which can be periodic (often hexagonal, but sometimes rectangular or triangular) or random (as in Voronoi honeycombs. Foams have polyhedral cells, typically without a repeating unit cell. Open-cell foams are solid at the edges only, while closed-cell foams have solid faces (Gibson, 2012). Integrating the cellular feature and osmotic pressurization mechanism can provide the ability to achieve differential pressurization for more complicated deformations (Li and Wang, 2016).

Fibrous cell wall materials (macro-level)

Plant cell walls are fibrous in nature, non-homogenous membrane, consisting layers of four basic building blocks: cellulose (the main structural fibre of the plant kingdom) hemicellulose, lignin and pectin. Each fiber has a complex, layered structure consisting of a thin primary wall encircling a secondary wall. The secondary wall is made up of three layers and the thick middle layer determines the mechanical properties of the fiber (Kalia *et al.*, 2011). Although the microstructure of plant cell walls varies in different types of plants (Gibson, 2012), all cell walls are composites of cellulose fibrils and a partially cellulosic matrix material. They are assembled into three major architectures: parallel fibrillar, sheet-like, and bulk. Microfibrillar angle is defined as the angle between fiber axis and microfibrils, and it was found to be a crucial factor in determining the mechanical properties of plant organs (Kalia *et al.*, 2011). For example, in bilayers, differential swelling of neighbouring tissues with dissimilar microfibril angle and/or degree of matrix swelling leads to reversible shape changes (Brule *et al.*, 2016). In summary, Cellulose orientation in plant cells direct organ actuation.

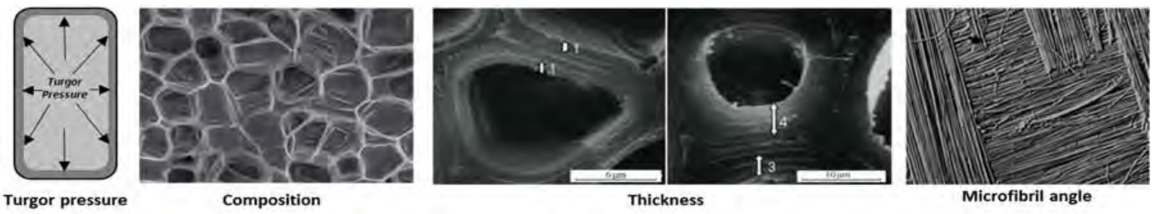


Figure 4. Cell and cell wall level.

Structural systems in engineering

The employment of elasticity within a structure facilitates not only the generation of complex geometries, but also creates elastic kinetic structures. Plant flexibility, represent a compliant mechanism that reduces the number of mechanical parts through integrating mechanical actuation into the materials themselves. (Schleicher, 2016). Howell (2001) defined Compliant Mechanisms as mechanisms that gain their motion from the deflection of elastic members and transforms the kinetic energy to strain energy in the members and then transforms it back to the kinetic energy (Howell, 2001). Compliant mechanisms combine strength with elasticity and gain some of their mobility from flexible members deflection rather than only from movable joints (Howell, 2001; Schleicher, 2016). In pliable systems the deformation behaviour of individual elements is constrained by their neighbouring elements. The linking of these elements allows the transmission of forces and torque (Schleicher *et al.*, 2011). Thus the deformation of one element will result in the deformation of the adjacent element. This relationship can be used to build up a cascading deformation movement. Pliable structures are based on elastic deformation as well as on the fact that it can convert between different stable configurations (Vergauwen *et al.*, 2017).

Bending-active structures are pliable constructions, which generate their geometrical form and their system rigidity by elastically deforming their members (Schleicher *et al.*, 2011). Bending-active structures, defined by Lienhard as structural systems that include curved beam or shell elements which base their geometry on the elastic deformation initially planar configuration. Yet, most bending-active structures are designed to bear loads and to be stiff only in their final configuration (Lienhard, 2014). Some researchers combine folding (plastic deformation) and bending (elastic deformation) using Curved-line folding to design efficient kinetic system. Curved-line folding is the act of folding paper along a curved crease pattern in order to create a 3D shape. (Vergauwen *et al.*, 2014) demonstrates how the choice of the composition of the crease pattern, the curvature of the creases and the Length–Thickness Ratio affect the resulting kinetic. In addition, Vergauwen *et al.* (2017) introduced the secondary layer principle (Bilayering) to perfectly control the folding motion by changing the distance between the two layers, which drive the layers to tension and pull into the desired position. On the whole, the selection of the composition, the structural behaviour and material have a great responsibility on the actuation system.

Applications of kinetic solar shadings

Some projects link kinetic design with biomimicry; from the selection and investigation of plant movements to the abstraction methods which were developed to translate plant movements into hinge-less elastic kinetics for deployable structures.

(Project A) The Flectofin® façade was developed by a team; from Plant Biomechanics Group (PBG) and the Institute of Building Structures and Structural Design (ITKE). A sun-shading system for complex building facades was inspired by the elastic deformation behaviour of the Bird-Of-Paradise flower. It is based on the valvular pollination mechanism of the Bird-Of Paradise flower. The logic of curved line folding was discovered accidentally from manufacturing tolerances but is understood as a key to the function of the mechanism. The curved-line folding kinematics was informed by the rapid trap closure mechanism of the carnivorous waterwheel plant (Lienhard *et al.*, 2010; Lienhard *et al.*, 2011; Lienhard, 2014).

(Project B) The Thematic Pavilion at the EXPO 2012 trade-fair in Yeosu, Korea was inspired by Flectofin® concept. It was proven that up-scaling of the basic principle is possible.

It is magnified to the large scale of 108 individual GFRP lamellas with varying heights that are deformed by controlled buckling. The skin can adapt to light and physical building conditions.

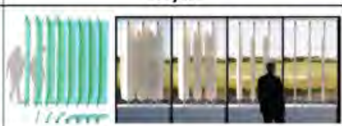
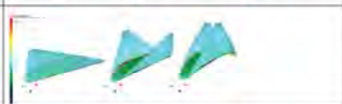
(Project C) was inspired by Aldrovanda vesiculosa. This aquatic carnivorous plant has a quick and reversible snapping motion. The movement is hydraulically driven by a central surface with a midrib, which cause a bidirectional change (Schleicher et al., 2015).

(Project D) The Lily mechanism was inspired by the compliant mechanism in the flower of Lilium casablanca (Liliaceae). The movement of the plant organ is based on unidirectional changes at the periphery caused by differential edge growth. Since the movement driver is based on internal changes of the material state, a temperature-controlled actuator that enforces edge expansion was simulated (Schleicher et al., 2015).

(Project E) Hygroskin project is developed by another team from the Institute for Computational Design (ICD), Achim menges in collaboration with Oliver david krieg and Steffen Reichert, presented a comprehensive development of smart skins based on the biomimetic transfer of hygroscopic actuation of plant cones. The shape change of wood was utilized to develop humidity responsive, integrated technical system (Reichert et al., 2015).

(Project F) studied the same mechanism of hygromorphic (moisture-sensitive) materials by (Holstov *et al.*, 2015) to produce low-tech low-cost adaptive systems by deploying materials with embedded responsive properties. A prototype of a responsive umbrella canopy consists of triangular panels with 7 different types of active layers.

Table 1. Summary of Bio-inspired skin systems.

	Project name	Project	Plant-Inspired	Biomimetic Methodological Approaches	Actuation mechanism
Project A	Flectofin		Bird-Of-Paradise (Strelitzia reginae, Strelitziaceae)	'Bottom-up-approach'	Valvular pollination mechanism
Project B	Thematic Pavilion				Elastic mechanism based on structural failure (buckling).
Project C	Lily Mechanism		Lilium casablanca	'Bottom-up-approach'	Differential edge growth in the tepals
Project D	Aldrovanda vesiculosa		Aldrovanda vesiculosa (Droseraceae)	'Bottom-up-approach'	Hydraulically driven by a central surface with a midrib
Project E	Hygroskin		Pine cone	'Bottom-up-approach'	Hygroscopic actuation (shrinkage and swelling wood)
Project F	Hygromorphic responsive umbrella		Conifer cones (e.g. spruce and pine cones)	'Top-down-approach'	Hygroscopic actuation (shrinkage and swelling wood)

Conclusion

The inability of contemporary adaptive skin systems to meet performance and cost efficiency requirements is a result of their excessive dependence on mechanical components which is associated with increased complexity and cost. In contrast, plant-inspired skins present an alternative approach of soft mechanics which provide opportunities for design of low-cost low-tech adaptive skins achieving dynamic behaviour by means of passive response. The current study has provided an understanding for the response mechanism of plants and principles for selection of their configuration. A number of morphological and compositional parameters affecting plant movements have been discussed across multiple scales ranging from tissues to cells and cell walls. The core principles of bi-layering have been extracted and discussed to develop Plant-inspired hinge-less kinetic skins. Future research could focus on development of efficient strategies; such as Bi-stability for practical application.

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Design to Thrive

An inquiry on residential furniture market in terms of innovative technologies and materials

Elnaz Farjami[1], Ozlem Olgaç Türker[2]

[1.] Res. Assist. Elnaz Farjami, Department of Architecture, Eastern Mediterranean University, Famagusta, north Cyprus. elnaz.farjami@cc.emu.edu.tr
[2.] Assoc. Prof. Dr. Özlem Olgaç Türker, Department of Interior Architecture, Eastern Mediterranean University, Famagusta, north Cyprus. ozlem.olgac@emu.edu.tr

Abstract: Innovative technologies in residential furniture design are important for improving the quality of future life. Material characteristics changed their old role of being less important in design, to a new functional performance after the Industrial Revolution. Innovative materials (smart / green) are believed to affect various aspects of contemporary design industry deeply, at all scales such as furniture, interior design, architecture and urban design. Nano technology serving smart materials is expected to change our environment, so it is necessary to take advantage of it and produce healthier, comfortable and humane materials, by considering all aspects of sustainable design and manufacturing. The aim of this study is an investigation on the usage frequency of innovative materials in residential furniture which is less than the expectations due to high cost or lack of knowledge etc. and extracts the positive features for residential furniture. The residential furniture in professional market is scanned through a selected international furniture fair, which collects a high number of companies from all around the world. Through this way, the study is expected to inspire the development, as well as the spread of usage of innovative materials in residential furniture.

Keywords: innovative materials, technology, residential furniture, green materials, smart materials

Introduction

Based on the definition of sustainability including energy efficiency, which is applicable in all scales of design, innovative technology is upgrading rapidly. Innovative technology provides various solutions and opportunities for human lives, environment and future lifestyle. By making innovations, there is a number of concerns such as maintaining environmental quality and extending the life-time; adapting and adjusting with the least disruption for other activities; low energy and material consumption, and low cost (Nakib, F. 2010).

This embodied energy, which is used during the material production processes, has different approaches in various types of materials, e.g. plastics, concrete and steel have higher amount of embodied energy in material construction as opposed to natural materials as timber and stone. Additionally, one of the most significant criteria to achieve sustainability is the volume of emission of toxic gases, which is used during the material usage period and production processes. Moreover, the right choice of sustainable materials is a vital point in human health issues (Onaran, B., 2009; Aktas, G. G., 2012).

Furniture as one of the main elements in interior design issues, has two main concerns in sustainability context, which are the long term usage and the materials used in production process. Accordingly, the selected materials for both building and furniture can be selected from the ones which are manufactured efficiently by concerning the energy and material consumption from renewable sources to make long-lasting, recycled materials and not to give out the indoor contaminants. Local, natural and green material can be designed in order to improve the material and energy efficiency in interior elements, comfort, aesthetics, economical issues and ecology (Onaran, B. 2009; Aktaş, G. G., 2012).

The frequency of using innovative technology and materials in residential furniture is less than the expectations due to reasons as high cost or lack of knowledge. The questions to discuss are: How do the innovative materials, including both smart and green materials, affect the contemporary residential furniture? Is the rising amount of research on innovations in materials, reflected to residential furniture market?

The aim of this study is an investigation on the usage frequency of innovative materials such as smart and green materials, in residential furniture market. In order to achieve this aim, a wide range of the aspects of innovative materials and the direct relationships with the residential furniture is explored. Moreover, a number of suggestions and recommendations about increasing the functionality of applying smart and green materials on residential furniture is discussed in conclusion.

Due to the lack of enough case studies to find out the exact types of innovative materials that the companies are applying, researchers are rely on commercial websites to collect the required data. The residential furniture in professional market has been scanned through a selected international furniture fair, which collects a high number of companies from all around the world. Keywords which are related to the features of innovative technology and materials are extracted from literature surveys such as books, articles, papers on innovative furniture materials.

Innovations in Residential Furniture:

Furniture design is an interdisciplinary science since it is related to humanities, applied art and good knowledge of working with material and manufacturing method that leads to have broad range of designing rules (Postell, 2012). The periods until industrial revolution made a simple connection between materials and architecture. The way that different materials used was for their practicality, availability, decorative characteristics and forms (Addington & Schodek, 2005). Within improvement processes, 18th century holds an important step, where designers started to think about flexibility and adaptability in furniture as a concept of sustainability. Furniture design depends on various factors such as insight, judgment, designing proficiency, engineering rules and good information of rules for problem solving. Different requirements for furniture design are vision, idea and obligation to satisfy the user. However, by using contemporary technologies in furniture production to make them sustainable and easy to use, clean, move, and change, user satisfaction increases (Broekhuizen, 2012; Ritter, 2007).

The environment has the capability of surviving from some of the human action without leading any harm (Field III, 2001). The contemporary developments based on new technology introduces innovative furniture. These new systems improve the quality of life, and ecologic character Hence, in order to accomplish the aim of the study, the categories related to innovative furniture are classified below to be searched on web sites of companies:

Smart:

- Nano-materials: Inorganic, Fullerenes, Graphene, Nano-crystals, …
- Nano-coating materials: Polypropylene, Polyethylene, sustainable coating, …

Green materials:

- Natural eco-friendly materials: Bamboo, Original wood, Health impacts
- Recycled materials: Salvage, Reusable, Rebuilt, Eco-friendly
- Nature-friendly design, packaging.

Smart Materials in Residential Furniture

There are widespread types of Nano-technology for different activities in furniture industry. Recently, the Nano-materials in furniture are considered by many contemporary furniture companies and factories (Broekhuizen, 2012). Nano-technology is used for product and material development. Applying Nano-materials is a core level for each part of furniture (Berger, 2013). Nano-materials or nano-enhanced materials have essential roles to create smart furniture for various purposes (Broekhuizen, 2012).

Nano-materials used in residential furniture

Nano-technology is believed to change our environment deeply at all scales, as object, interior space, building, and urban design, so it is necessary to take advantage of it and produce healthier, comfortable, and humane materials. Nowadays, Nano-technology has provided a lot of capabilities such as manipulation, changing and even designing around objects and their materials in the scale of Nano (0.0000001-0.000000001 m) since different behaviours of materials can be controlled accurately in Nano-scale (Niroumand et al, 2013). When Nano-materials are made professionally, they may end up with high costs.

Some features expected to be obtained from Nano-materials are listed as: easy to clean; to prevent bacteria to enter; focus on the scratches on glass or wooden furniture; protect materials from UV-protective coating; lower consumption; easy to change; easy to take form (they are plastic and can be coloured so easy); safety (private or public spaces); novel flame retarding methods (fire resistance); more durable (long life); stronger (stiffness behaviour); and self-healing (having a good characteristic of reconstructing their mechanical properties when damaged); sustainable characteristic and processes of production; lighter materials; and various transparency levels (Gilman, 2009; Broekhuizen, 2012; B. A¨ıssa et al, 2012; Karana et al, 2013).

Composites

There are some steps of activities for both plastic and wood composites. Wood composites like Nano wood fibres need to improve and optimize the benefits of using composite materials, though it is not achieved in markets, indeed hereof costly and not effective enough. The effectiveness level to attach Nano composites on fibres to achieve the best surface product is at the constructive level. Nano-cellulose fibres are applied to the wood composites and make them a renewable material; hence, it will be used as finding composite layer material for reaching more sustainable level (Broekhuizen, 2012). Society of Plastic Engineers (2012) list some features as: Improving the strength and the structure of materials (durability), coating preservation (durability), wear resistance (durability), safety, flare determent (fire resistance).

Concrete

One of the self-cleaning factor in concrete would be reliable with UHPC (Ultra High Performance Concrete) that is made by silica fame and 24nano- TIO^2. On the whole, the concrete that is used for furniture in kitchen should have enough density UHPC to prevent spots and water. On the contrary, UHPC will be used in new lighter furniture products or with slim size (Broekhuizen, 2012)

Metal

Nano-metal amelioration accrued when the modification is in the structure level instead of surface edit level, through this proses, metal will be sustainable and durable (Broekhuizen, 2012). Surface cladding metals are not stable since they can easily be damaged during usage. But their advantage is that they can be recycled by melting, however they have the hazard of emitting dioxins since they are coated by polyvinyl chloride (Berger, 2013).

Nano-Coating in Residential Furniture

By regarding Nano material technology as an expensive but new science, Nano-coating technique has been concerned and applied on current developments. Basically, Nano-coatings are using nano-materials in particular application. Meanwhile they have the ability to gain scratch resistance, anti-graffiti, easy to clean and water repellent, UV/ light stability, self-cleaning, anti-microbial / bactericidal, fire-resistance properties (Broekhuizen, 2012).

Glass

The function of new technology is applying a coating on each kind of normal glass which has 98% effect. There are different types of Nano-glass such as non-reflectivity, privacy-glass, thermal isolation and biocide glass, which can be implemented for various applications, i.e. glass-cabinets, lamps, tables, office furniture or medical furniture. To achieve a privacy glass, there is a liquid crystal between the glass sandwich layers, which creates a high opacity. A thin layer of metal oxides makes one kind of glass that can collect infrared radiation. Furniture surface should be controlled in interior space about preventing slow heat up around heat-sources (Broekhuizen, 2012).

Wood

Nano-technology is applied to the forestry wood production to achieve more sustainable wood and protect them from fungi, pest and biocides. These processes can be like co-biocides to protect the deep inside of the wood in a system named Nano-cannier. Besides, wood can be protected by Nano-metals, such as cooper-zinc and Nano-silver that release biotical caused by oxide in the long-term. An important matter about long life of wood and wood composite is their surface swelling when they are exposed to water, even by cleaning. In addition, pesticides that are used during wood growth may still be remaining in usage stage. Nano-technology is appropriate to increase sustainability in some wood products like MDT or OBS (Mantanis, Papadopoulos, 2010; Broekhuizen, 2012).

Textiles

One of the flexible and comfortable materials in designing and changing furniture is textiles (Addington & Schodek, 2005). Anti-stain furniture textile can be produced by coating the material with liquid-glass, i.e. coating by Nano-titanium dioxide or by Teflon. The textile fibres can be individually impregnated. To achieve another biotical textile, 'Nano-silver coating' which can be chemically connected to the textile is used. Besides, durability and quality of textiles are affected from three types of Nano-silver that are 'loose coating'. Nano-clay is a class of Nano-material which is known to have fire resistant characteristic. These different types of textile treatments do largely affect the quality and the durability of the textile's performance. (Broekhuizen, 2012).

Adhesives

Generally, adhesives in furniture production have been used in spite of insufficient information about their optimization that will be possible with Nano-materials. In addition, one of the effective factors in furniture durability is about the interplay between strand surface conduction and glue constitution to preserve the base from the erosion and decrease glue usage, the dispensation coating has been effective to keep Nano-roughening (Broekhuizen, 2012).

Green Materials in residential furniture

Green materials used in residential furniture are categorized under three sub-titles as natural eco-friendly materials, recycled materials and environmentally-friendly design / production / packaging / transportation.

Natural Eco-friendly Materials

Since ancient times, Chinese cabinetmaker took advantage of solid bamboos as a sustainable material to avoid using any screws and nails. Another eco-friendly material which gives furniture shine and aesthetic appearance is mango wood. One of the bamboo properties, which make it to be convenient and useful in bath and kitchen components is its anti-bacterial characteristic (Crateandbarrel, 2014) in addition to concrete reinforcement (Adams, 1998). Characteristically, bamboo is a kind of fast-growing natural grass that can be grown in different climates, both hot and cold in all over the world, Latin America, Africa and Asia with economical cost (Milani.B, 2005; Architecture in development, 2012).

Mango wood is very popular because of its natural hardwood and spectacular sustainability in comparison with oak and teak. It belongs to the sumac family of trees and it is evergreen. Distributed from India, now it is cultivated in South-East Asia, Australia and South Pacific Islands (Melange Decoration, 2013).

Recycled materials

The history of the salvaging material goes back to a long time before Romans. Nowadays science is used in order to investigate salvage materials. If the materials are unusable, recycling can be an option in order to optimize them. Materials such as clean timber, metals, gypsum board, and cardboard or paper can be mentioned among recyclable materials. A pre-recycling procedure, which is necessary in some cases, is to divide waste hauling at site which also decreases pollution. Advantages of salvage and recycled materials are listed as (Seattle public utilities associate, 2013): ‘Give usable items another life’; ‘save money’; ‘support the local material reuse and recycling industry’; ‘reduce natural resource use’; ‘cut greenhouse gas emissions’; ‘earn green building rating system (e.g., Built Green™, LEED™) points’; ‘send less waste to the landfill’.

Environmental friendly design / production / packaging

By using environmentally-friendly approaches in design, production, packaging and transformation of furniture in companies, contribute to sustainability. They are extending the life of furniture to reduce waste by reducing consumption. Besides, energy efficiency is used in production of furniture. Furthermore, the companies are also taking care of forests and planting more trees in place of the used timbers and by having fewer pieces of furniture for various functions / ages to reduce waste materials through a smaller number of furniture. As for transformation, using small packaging to take little space in transport and storage will be part of environment friendly transportation.

Exploration of ICFF 2015

In order to investigate the reflections of the recent developments in residential furniture industry, one of the international furniture fairs which include the highest number of companies attended from all around the world, is selected as ICFF 2015 in USA with 723 companies. Accordingly, the related keywords for innovative materials such as smart and green materials, have been scanned through companies to distinguish the variety of features among them. For the investigation, the categories of residential furniture are classified as: seating, including single seat (chair), multiple seats (sofa, bench), dining (dining table, buffet), Storage (bookcase, closet, drawers, and shelves, cabinet), sleeping or lying (bed, bunk bed, and sofa bed), study (desk, chair), entertainment (billiard table, TV table).

Through this analysis, the study is expected to reveal the usage frequency of innovative materials and hence, inspire the new developments as well as the spread of usage of innovative technology and materials in residential furniture. As it is analysed in Table 6 below, each keyword has been searched among selected companies according to their residential furniture products. In the search of innovative furniture material keywords within furniture category, two companies were found, whereas innovative furniture material keyword within seating category was 15, Table 1.

Table 1. Distinguish the number of companies which produce residential furniture by using Innovative technology and Innovative material technology

Company	**Innovative Furniture Materials**				
	Smart material		**Green material**		
	Nano-Material	Nano-coating	Natural Eco-friendly Materials	Recycled Materials	Eco-Friendly Design / Production / Packaging
Furniture	1	1	0	0	0
Seating	0	0	10	4	1
Total	1	1	10	4	1
	17				

By considering the features among seventeen companies with either smart and / or green innovative materials, ten of them are selected by random sampling to investigate the distribution of sub-categories in innovative residential furniture in ICFF 2015, Table 2, 3. The related keywords are searched within WEB pages of selected companies to find out the distribution of features.

Table 2. Various keywords of innovative materials characteristics which are searched in selected companies Web sites

Innovative Residential Furniture Materials			
	category	**Sub-category**	**Related keywords**
Innovative Furniture material	Smart	Nano Material:	Energy efficient, sustainable, smart, transforming to sustainable material, durable, easy-cleaning, safety, composite, property-changing, phase-changing materials (PCM), colour-changing materials, electro generating, light emitting, multipurpose materials,
		Nano- enhanced:	Reclaimed polypropylene, polyurethane, sustainable coating, UV-protection, durable, child safety, easy-cleaning, anti-microbial, safety
	Green	Eco-friendly material (natural or artificial)	Natural, earth friendly, timber absorbs carbon dioxide, natural materials, green natural finishes, sustainable timber, bamboo, mango, environmentally-friendly, long-lasting, last for generations, caring for the environment, protect environment, environmentally responsible, environmentally responsive, eco-friendly, sustain environment, sustainable materials, environment friendly finish, water-based finishes, reduce environmental impact, heavy metal free
		Recycled:	Recycled ground, re-adored, recycled cosmopolitan glass, salvage tiles, salvage wood, recycled aluminium, recycled plants, recycled obsolete, salvage specialist, wood waste, re-usable, re-built, eco-friendly
		Eco-friendly production / packaging:	Energy efficient factory, energy efficient production, sustained yield forestry practice, innovative production, eco-friendly packaging

Table 3. A comparative analysis of selected innovative residential furniture companies from ICFF-2015.

Innovative Residential Furniture					
Residential Furniture Companies from ICFF 2015	Innovative Furniture Materials				
	Smart materials		Green material		
	Nano-Material	**Nano Enhanced**	**Natural Eco-friendly Material**	**Recycled material**	**Eco-Friendly production and packaging**
Company 1			√	√	
Company 2				√	
Company 3			√	√	
Company 4			√		√
Company 5			√	√	
Company 6	√	√	√	√	√
Company 7			√		
Company 8			√		
Company 9			√		√
Company 10			√	√	

Although contemporary researches focus on sustainability issues on contemporary residential furniture design, it has been observed through the analysis, that only a limited number of companies have all sub-categories of innovative materials. In other words, the frequency of using innovative materials in residential furniture is less than expectations. Moreover, it has been observed that the use of smart materials such as Nano-materials or Nano-enhanced materials in residential furniture is limited with only one company in ICFF 2015, whereas the majority of using green materials as a sub-category of innovative materials mainly gather around natural eco-friendly materials.

Conclusion

Generally, environmental sensitivity and quality for future furniture have main indications, anti-bacterial, water pellet, high resistance to scratch and UV protection, which are beneficial points of innovative materials and covering layers. Another concern of contemporary furniture design is being sustainable, which addresses the environmental impacts of furniture products on the ecology of the planet by considering all aspects of design and manufacturing. Nano-technology serving to smart materials is expected to change our environment, so it is necessary to take advantage of it and produce healthier, comfortable and humane materials. Nano-materials and furniture work together in order to complete each other into a new system.

Table 4. Smart and green material features that are mentioned in WEB sites of case studies

Smart and Green material Features
▪ Organic shapes and ease-of-use to enhance the spontaneous
▪ Use eco-friendly materials that will sustain families and the environment for many years to come.
▪ use of more environmentally-friendly water based finishes
▪ Natural products are made with natural earth friendly materials
▪ focuses on applying a uniquely artistic and environmentally responsible approach to interior surface design
▪ easy to clean and can be customized using embossing
▪ energy efficient, environmentally-friendly, protect environment, environmentally responsible
▪ Natural finishes, Caring for the environment, natural materials, natural earth friendly
▪ Smart materials, polypropylene, sustainability, woven metallic polyurethane

For enlightening future studies and involving innovative technology and materials in the production processes of residential furniture, a deeper analysis of some companies which include the majority of sub-categories is accomplished in Table 4. There are some beneficial features explored from selected companies which are producing residential furniture by using innovative materials (smart and green materials).

The beneficial features explored above need to be included in future production processes of innovative residential furniture by using innovative materials (smart and green materials). It has been investigated that the frequency of using green materials is higher than using smart materials in recent residential furniture production worldwide. The higher usage of green materials needs to shift towards togetherness of both smart materials (Nano / Nano-enhanced) and green materials (Recycled / Natural / Eco-friendly production and packaging) in order to achieve more durable and sustainable production quality.

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An investigation into the inclusion of polymers to low carbon clay-based external renders and the effect on waterproofing and vapor permeability

Androniki Giannatou[1,2] Tom Robinson[1]

[1]Graduate School of Environment, Centre for Alternative Technology, Wales, UK
[2]School of Architecture, National Technical University of Athens, Athens, Greece

Abstract: External renders work as a safeguard to ensure not only water proofing but energy efficiency of buildings. BRE, NIHE or IEA have conducted research to estimate energy savings from wide scale retroffitings. Energy efficiency was reduced by up to 50%, due to insulation failures in external walls, caused by rain penetration and other reasons. An external render combining very low Water Absorption for rain penetration, high Vapor Permeability for breathability, and low embodied energy, is lacking in current UK market. Therefore, report explores a potential alternative to lime render, based on an innovative composite of nanoclay and waterproofing polymeric additives. 15 different clay-based specimens with 4 waterproofing polymeric agents and 2 breathable organic aggregates were tested for their physical (density, porosity) and hygric properties (Water absorption, Vapour permeability) using gravimetric and British Standards laboratory tests. 3 out of 15 specimens achieved the desired criteria of notably low absorption rates and high VP, outperforming those of known lime renders of UK market and relevant clay renders of existing academic research. The results indicate that they have a potential application as low carbon, highly waterproofing, breathable and compostable render solution, either in traditional porous buildings or in new structures.

Keywords: Clay-based render, nanoclay bio-polymeric composites, water absorption, vapour permeability

Introduction

External renders work as a safeguard to ensure water proofing and in many cases energy efficiency of buildings. Due to UK wide scale energy retrofitting in the last decade, organisations such as BRE (Stirling, 2001), NIHE (2014, p.18) or IEA (2007) have conducted research to estimate energy savings as a result of interventions. They concluded that buildings energy efficiency was reduced by up to 50%, due to insulation failures in external walls, caused by rain penetration. Mould and fungus were also present.

Current market renders exhibit similar limitations as traditional ones. Specifically, although cement renders display low Water Absorption (Wa), their low vapour permeability (VP) hinders moisture evaporation. Furthermore crystallization of soluble sulphate salts enhances cracking (Kopacz et al, 2013; Wilk et al, 2013). Although Lime renders display higher VP, they exhibit higher Wa than cement renders (Straube, no date), leading to cement mortar cracks (Izaguirre et al, 2009 ; Nezerka et al, 2014). New nanotechnology and silicon-based renders provide high waterproofing, but low VP (Manoudis, 2009). In UK with high precipitation and porous structures an external render, which combines very low Wa properties to prevent rain penetration, with a high VP, to ensure breathability of the building and low embodied energy to reduce emissions, is lacking in current market and building practice.

On the other hand clay renders and structures have stood the test of time (NCCHS, 2014). Examples in UK is the ''wattle and daub'' construction system based on clay, sand, animal dung and straw applied on wooden lattice (Bowyer 1973, p.48-51 ; Graham 2003) or a plaster finish with clay, chopped straw, hay and dung added to daub (Davey 1961, p.40-41). In addition, In a Life Cycle Assessment clay render exhibits a holistic ecological profile providing savings in Energy (2 times), CO2 emissions (7 times) and in environmental contamination of air, water and soil (2.5 times) (Melia et al, 2014)(Table 1).

Table 1. Earth, lime and cement renders ecological profile (Melia et al 2014).

Renders	Cumulated Energy demand (MJ)	Carbon Emissions (kg CO2eq)	Environmental footprint (mPt)	Ecological footprint (m2 yr)
	(Cradle to Gate Embodied Energy)	(Cradle to Gate emissions)	(Environmental impact on 19 indicators in air, water, and soil)	(land occupation for the material extraction, production, cultivation,etc)
earth renders	29.1	1.22	182	4.2
lime renders	63.2	7.64	501	19.4
cement renders	54.6	7.03	454	18.2

Acknowledging all the above, this research tested a potential alternative to external lime render, based on a clay binder of one synthesis, hoping to cover a gap in current market or in literature. The innovative ecological nanoclay composite was enhanced with four polymers (one synthetic and three organic) for waterproofing and two aggregates for breathability. The physical and hygric properties were compared to air-lime render and to a limited number of well known UK commercial lime products. The contribution of polymers and aggregates was also identified. The research may share important data, since published data is extremely limited on a) clay waterproofing agents (Minke 2006 ; Straube no date) b) renewable ''green'' organic polymers (bio-plastics) in construction industry, as opposed to petrol-based plastics c) nanoclay bio-composites in renders. However, bibliography for bio-polymers is mostly associated with biodegradable films in food packaging industry, (Henriette de Azeredo, 2009) where casein polymer displays waterproofing (Cheema,2015) and vapor permeable performance (Bonnaillie et al 2014)while cornstarch polymer displays low porosity (Srikaeo et al,2005) plasticising properties but high water absorption. The research exploited the nanoscale (1nm) electric structure of clay as negative charged platelets in order to bond it with positive charged polymers, thus block water molecules (0,3-1mm) while allow vapor(1nm) to pass.

Methodology

15 types of clay-based specimens (45 replicates) enhanced with 4 waterproofing polymers (based on siloxane, casein, cornstarch, bioplastic) and 2 breathable additives (perlite, straw) (Table2) and one air-lime render (1:3) as control render (3 replicates), are tested for their Physical (Density, %Open Porosity) and Hygric properties (Wa, Vp, water penetration depth) are compared. The above tests are small part of a larger Thesis research, testing crucial properties in market industry (Giannatou, 2016). The research is linked with current literature. Specifically, the soil type used, its constituents, the ratios of its basic Category (Category A) and its control render(A0) (Table 2) align with those that G.Minke used in an educational workshop conducted in Greece (2008) in collaboration with Anelixi, an ecological research association. The research continues above work testing A0, while differentiates using different composition in the same waterproofing agents (casein mix, cornstarch mix) and adds 2 aggregates. All specimens have the same synthesis which is A0 composition. So new polymers and aggregates effect on Wa and Vp, which was the research target, is measured by comparing relevant specimens of different categories. As for constituents, sand mixture incorporated three distinctly different particle sizes.

Hydrophobic, siloxane-based, synthetic polymer emulsion (400ml/m²) is applied in two layers, after the specimen dries. Organic polymer agents or bio-plastics (casein, cornstarch, bioplastic mixes) are produced under heat with the addition of positive ions (H,Na,Ca) in each solution with volume strictly not exceeding the 5%. Melt intercalation enhanced with manual shearing and compressing (Theng, 2012) is then used for the clay nano-composite production, intercalating positive charged polymers into clay negative sheets.

Table 2. Constituents and Ratios of specimens tested.

Specimen synthesis	**Code**				
Clay renders _A Category		**Clay renders _B Category**		**Clay renders _Γ Category**	
Basic(B) : 0 aggregate		**Basic(B) : 1 perlite**		**Basic(B) : 1 straw**	
Basic (B)	**A0**	B/perlite	**B0**	B/straw	**Γ0**
B/ siloxane coating	**A1**	B/perlite/ siloxane coating	**B1**	B/straw/ siloxane coating	**Γ1**
B/ corn starch mix	**A2**	B/perlite/ corn starch mix	**B2**	B/straw/ corn starch mix	**Γ2**
B/bioplastic mix	**A3**	B/perlite/bioplastic mix	**B3**	B/straw/bioplastic mix	**Γ3**
B/casein mix	**A4**	B/perlite/casein mix	**B4**	B/straw/casein mix	**Γ4**
Air-lime Render Control	**L**	**1 lime : 3 sand**			

The %Open Porosity (OP) (%ratio between the difference of saturated and dry mass of the specimen to its dry volume) examines all additives effect on the porous structure and the OP relation to Wa examines the value connection to waterproofing. Water absorption was tested in accordance with British Standard BS EN ISO 15148 (2002) guidelines. The test measures the rate of water absorption of a specimen by capillary action during 24hrs, and defines the water absorption coefficient (Aw=kg/m² sec ½). Specimens were sealed on sides (aluminium foil, 100% virgin beeswax) and stored at 28°c and 50%RH in the climate chamber to stabilize their total mass to 0.1%. They were submerged by 5mm in water cups and stored in a climate chamber(28°C, 50%RH) for 24hrs. 17 weightings during the 24hrs were recorded, instead of the 8 required by British Standards, to minimize error from 4% to 1.5% and form the Wa diagram in high precision.

VP testing (dry cup) measures the resistance (μ-value) in the vapor flow through a specimen in a steady state in accordance with BS EN ISO 12572(2001) and accuracy methods required. Specimens whose sides were primarily sealed with foil tape and wax, were sealed on a cup of similar diameter incorporating desiccant (CaCL2, size<3mm) and a USB data logger(°C, %RH) to measure the VP of stagnant air. All specimens were located in a climatic chamber (TAS,ECO 900) (23°C±5,50%±5RH) for 6 days. An electronic scale (±0.005gr) was used for specimens periodic weighting. The μ-value was measured as the ratio between the VP of stagnant air (inside a cup) and the VP of the specimen under23 ±5°C and 50±5%RH.

Results and Discussion

Physical properties

Density and Porosity

In 10 of 12 specimens the addition of polymers decreased their Density, except in the basics A1,Γ1 (Figure1). This suggests that they work as both light fillers and binders. In addition, casein polymer was found lighter as a filler compared to aggregates, such as perlite or straw. Specifically, comparing A0 density, to B0 and Γ0 which were aggregate-based, they reduced the A0 density less than the casein-based A4. Both aggregates did decrease Density of 11 of the 12 specimens, except the A1, performing as light fillers, aligning with relevant literature data (Straube, no date; Ashour et al, 2010 ; Minke, 2006, p. 49). All specimens displayed lower density from 4% to 26% compared to the research control lime render (1780kg/m3). Significant cause for lower density of the clay-based renders is that both polymers and aggregates (30–150 kg/m³) work as lighter fillers than sand (1300-2000 kg/m³).

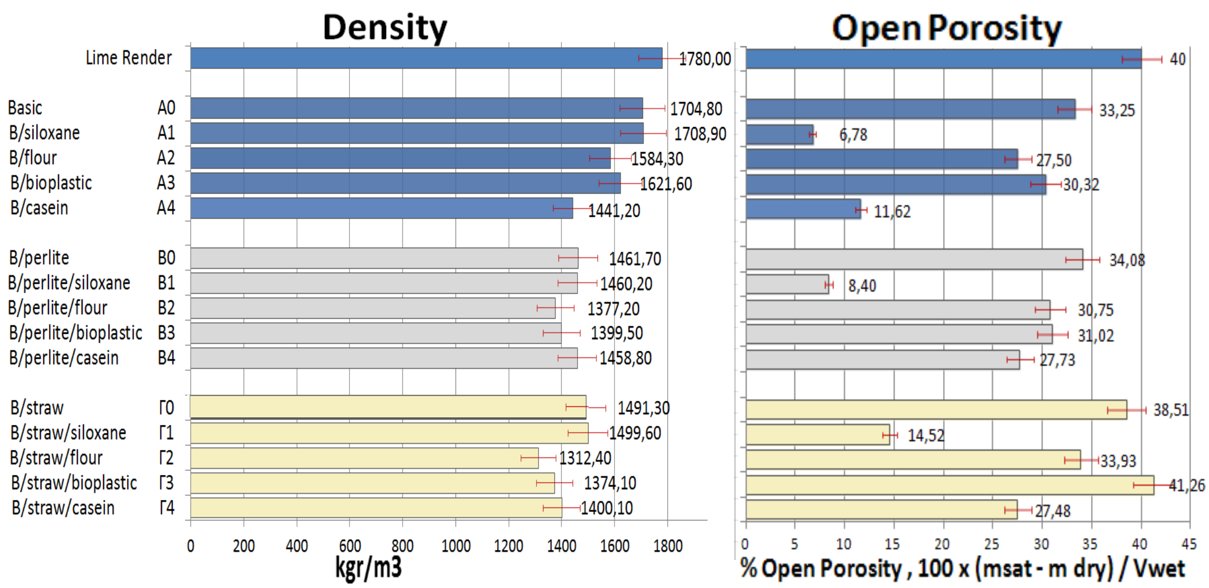


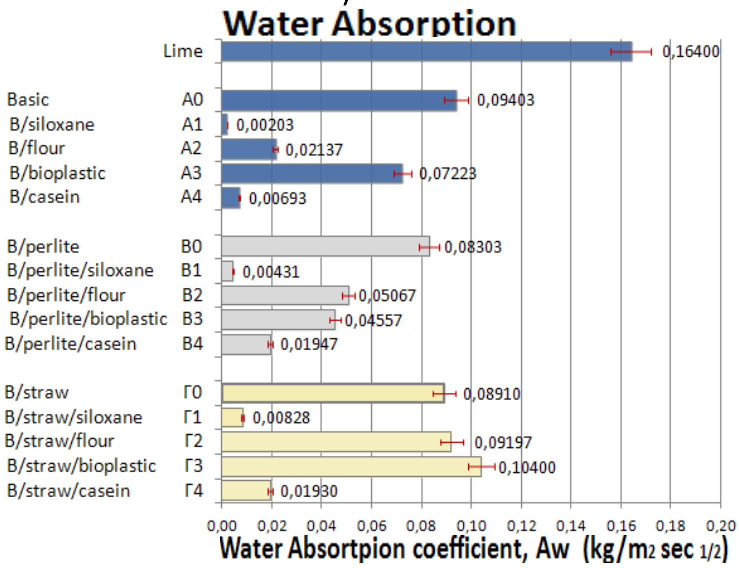
Figure 1. Density (kg/m³) and Open Porosity (%) values of specimens tested (Mean value, ±95Cl).

Polymers decreased the % Open Porosity of 11 out of 12 specimens except Γ3(Figure1). The highest %OP decrease was achieved by siloxane coating (A1,B1,Γ1)(62%-79%) and by the organic casein (A4,B4,Γ4) (28%-65%).This implies that polymers nano-structure turn them into high porosity reducers but not pore blockers (%OP>7%). Aggregates (perlite and straw) increased the porosity of all 10 poymer-based specimens, with straw exhibiting the higher increase in all categories (Γ1,Γ2,Γ3,Γ4) (15-136%) and perlite (B1,B2,B3,B4) the lower (2-138%). All of the above indicate that aggregates work detrimentally for the external renders porosity and potentially for their Wa. This is against existing orthodoxy, practice and market trend, where straw and hemp is frequently used in external renders. 13 out of 14 specimens displayed 45% to 255% lower porosity than lime, except Γ3. Siloxane and casein when mixed with Category A specimens, A1 and A4 skyrocketed their porosity reduction to 255.54% and 218.08% respectively (Figure1). Minke (2006) and Straube(no date) also tested siloxane to be a high porosity reducer on clay and cement respectively.

Hygric properties

Water Absorption

Polymers significantly decreased Wa for 10 out of 12 specimens by 23-96% compared to their non-glued Category Basic (Figure 2) displaying a significant waterproofing ability. Best sealers proved all siloxane mixes (A1,B1,Γ1)(90-96%) and all casein mixes (A4,B4,Γ4)(76-92%). Aggregates significantly increased Wa for 7 from 10 specimens by 26-178% compared to the relevant specimen of Category A incorporating the same polymer. This implies that perlite and straw combined with polymers work as water absorbers but alone in clay specimens (B0,Γ0) work as water reducers (5,25-11,70%) complying with current practice. In the literature, aggregates usually work as absorbers (Ashour, 2010; Minke, 2006). 13 to 14 specimens displayed lower Wa than A0 and 14 to 14 than lime render. Earth-based specimens proved to be better sealers by 36-97% compared to air lime render control. In fact the siloxane-based A1(0,00203 kg/m² sec½), and the casein-based A4 (0.00689 kg/m² sec½) exceeded most commercial renders performance (Table 3). Furthermore A1 met and A4 exceeded the performance of relevant specimens of Gernot Minke (2006) which displayed Wa 0.0 017 and 0.0117kg/m² sec½) respectively (Table 3).This aligns with current literature and goes against existing orthodoxy and market practice that associates clay renders with inner use only.



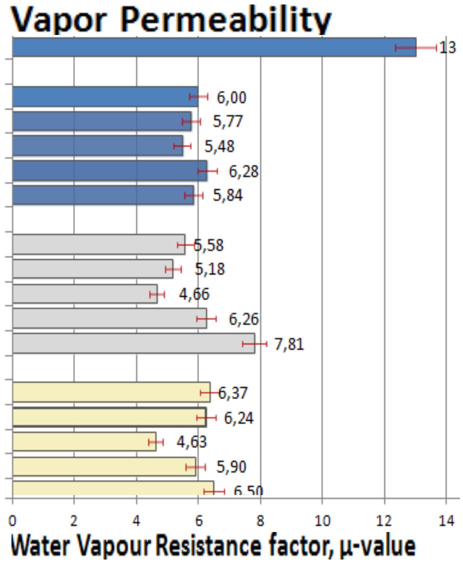
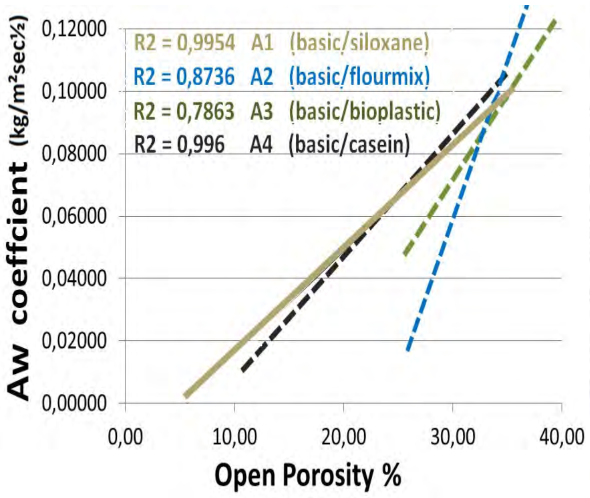


Figure 2.Water Absorption coefficient values, Aw (kg/m²sec½) of specimens tested (Mean value, ±95Cl).
Figure 3. Vapor Resistance factor values, μ (unitless) of specimens tested (Mean value, ±95Cl).



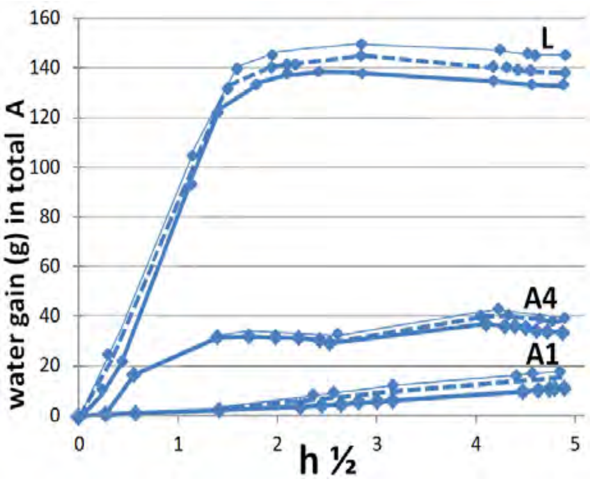


Figure 4. Relation of Water Absorption coefficient, Aw (kg/m²sec½) to %Open Porosity (Category A).
Figure 5. Water Absorption gain (g) per time, during the 24hrs Wa test.

Polymers inclusion did result in a strong positive Porosity/Wa correlation for 9 out of total 12 specimens, except for B2,Γ2,Γ3 (Giannatou, 2016)(Figure 4). This implied that polymers not only reduced the number and water size pores of the specimens, but this maybe among the reasons that turned them into waterproofing agents. Siloxane (A1,B1,Γ1) (R^2=0.95-0.99) and casein (A4,B4,Γ4)(R^2=0.92-0.99) had the strongest correlations in all 3 categories(Figure 4), experiencing the highest porosity reduction which implied that their polymers final porous system was the finest of all, closing specimens pores in a higher level. Category A specimens (A1,A2,A3,A4) displayed the strongest correlations of all categories (R=0.78-0.99) (Figure 4), and a higher waterproofing capacity implying that all polymers are more waterproofing, when specimens acquire no aggregates.

Specimens Wa performance was further examined by; a) measuring the water penetration depth of specimens after the Wa test by cross-sectioning b) assessing the Wa diagrams. In water penetration depth test air-Lime render was completely saturated (25mm) after 24hrs, while A1,B1 displayed no water penetration after 24hrs or 42hrs, and A4 which displayed 5,7mm(24hrs) and 10mm(42hrs) respectively (Figure 6). The siloxane based specimens (A1,B1) were light in color and weight, showing little signs of moisture. The casein based A4 displayed water ingress that has been blocked up to a distinct horizontal level (Figure 6). The Wa diagrams is concurrent with the above. Samples A1 and B1 displayed a very low but steady Wa rate since its siloxane hydrophobic coating repelled water, while the casein polymer performance in A4 seemed to have blocked water intrusion twice. The above relates to the known ‘’clay tortuous path’’ mechanism (Figure 7) (Henriette de Azeredo, 2009) where successful intercalation (insertion) of polymer into the clay stratification of horizontally bonded layers blocks water intrusion.

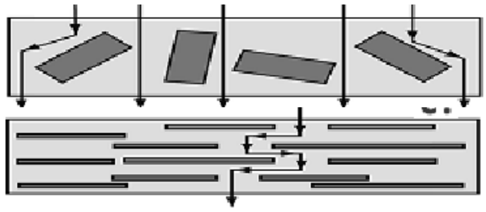


Figure 6. Depth of water penetration (mm) in the relevant test for A11,A21,A41.
Figure 7. Clay platelets versus polymer-clay platelets dispersion after compressing(Tortuous path).

Vapour Permeability

Paradoxically 11 out of 15 polymers did increase, instead of decrease the Vapor Permeability of their Basic specimen (2%-27%) working as vapor enhancers (Figure 3). In addition, some polymers and especially cornstarch mix when added to A0 increased VP more than even perlite(B0) or straw(Γ0). This implies that some glues could replace equally or even better perlite and especially straw to increase specimens VP property. Potential cause could be that most polymers reduce the pores sizes, and since they are hydrophilic they enhance attached vapor molecules velocity (0.2nm) according to Bernoulli law (Portella, 2009). From the 2 aggregates tested, perlite (μ- value=2) did increase the VP of all specimens (0.3%-15%) except the B4, but paradoxically straw decreased the VP of all (-11% --6%), except Γ2 and Γ3. This is logical and revealed that the clay-based specimen is highly Vapour Permeable by itself (μ- value<6) and straw is simply less (μ- value>6). No academic data has found straw (μ- value>6) to reduce specimens VP, given that most specimens in literature displayed (μ- value>6) (Minke, 2006; Ashour, 2010; Straube, no date). Also this is against existing orthodoxy and practice, since straw is always considered a VP enhancer for plaster and renders, which maybe not always be the case, in low μ-value specimens.

8 out of 14 specimens outperformed A0, and 15 out of 15 outperformed air-lime render, displaying higher VP between 39% to 64 % (Figure 3).Thus, they are considered highly VP agents. It was the polymers that primarily enhanced specimens VP, but furthermore the clay-based specimens synthesis was further reason, since A0 (the basic specimen of all categories) was 53.80% more vapor permeable than air-lime render control. In comparison to academic data, a notable finding is that the 3 best specimens tested by Gernot Minke(2006), the casein-based, the flour based and the siloxane based specimens (Table 3) displayed lower VP (μ=13) than the research relevant specimens (μ=5.18-6.27).

Furthermore, the research specimens displayed superior performance to widely used renders (Table 3).

Conclusions

Polymers decreased Density(10/12),%Open Porosity(11/12) and Wa (10/12) while increased VP (11/15) (Table 3). This implies that they worked beneficially as light fillers and binders, porosity reducers, strong waterproofers and VP enhancers at the same time. Furthermore, some proved better VP enhancers, than perlite and straw, meaning that they could replace them. The polymers contribution to porosity reduction, waterproofing and breathability increase implies that they decrease pore size, so as to block free water (0.3-1mm) but allow vapor (1nm) entrance. The synthetic polymer of siloxane and the degradable bio-polymer (bio-plastic) as caseinmix displayed the best performance. Although aggregates decreased density (11/ 12) they increased porosity (10/10) and Wa (7/10). As for VP perlite increased it (4/5) while straw decreased it (3/5). Since they proved to be porosity enhancers, water absorbers with mixed performance in VP, their performance proved detrimental in the end. As for clay-based specimens, they proved to be lighter (15/15), less porous (13/14), more waterproofing(14/14) and more vapour Permeable(15/15) than air-lime render (1:3) control.

Table 3. Wa and Vp performance of research renders compared to literature and market products.

EXTERNAL RENDER		Density	WA	μ
LITERATURE LIME RENDERS (TRADITIONAL 1:3)		(kg/m3)	(kg/m² sec½)	(unitless)
AIR-LIME (1:3) MINKE (2006)		1750 (dry)	0,154	11,00
AIR-LIME (1:3) STRAUBE (no date)		1748 (dry)	0,153	9,85
AIR-LIME (1:3) THESIS(2016)		1780 (dry)	0,190	13,00
LITERATURE CLAY RENDERS (RESEARCH RELEVANT)				clayey-silty
EARTH RENDER/SILOXANE (BS 15 Wacker)	**MINKE (2006)**	x	0,0017	12-14
EARTH RENDER/2 COATS (8 CASEIN:1 LIME)	**MINKE (2006)**	x	0,0117	12-14
EARTH RENDER (2% RYE FLOUR MX)	**MINKE (2006)**	x	0,019	12-14
EARTH RENDER	**STRAUBE (no date)**	1759 (dry)	0,068	7,03
EARTH RENDER MIX (5 LIMEWASH COATS)	**STRAUBE (no date)**	1408 (dry)	0,047	7,18
CLAY RENDER MIX (50% LIME BY VOLUME)	**STRAUBE (no date)**	1741 (dry)	0,092	7,26
MARKET LIME RENDERS				
MAPEI		1750 (bulk)	≤ 0,025	20,00
UNILIT		1800 (bulk)	≤ 0,006	10,00
KEIM		x	≤ 0,025	10,00
BAUMIT		x	≤ 0,025	10,00
LIMETEC		1600	> 0,12	< 8
REMMERS		1100	0,129	<15
THESIS CLAY RENDERS				
A1 (SILOXANE-CLAY RENDER)		1708 (dry)	0,00203	5,77
B1 (SILOXANE-CLAY RENDER)		1440 (dry)	0,00403	5,18
A4 (CASEIN-CLAY RENDER)		1441 (dry)	0,00698	5,84
Γ1 (SILOXANE-CLAY RENDER)		1499 (dry)	0,00803	6,24
A2 (FLOUR-CLAY RENDER)		1584 (dry)	0,021	5,48

A notable research finding is that research specimens (A1,B1,A4) outperformed both in Wa and Vp a) similar specimens in literature and, b) current commercial lime renders in UK Market (Table3). Regarding the first, A1 siloxane-based specimen displayed almost equal Wa (0.002 kg/m² sec½) to G. Minke(2006) relevant specimen (0.0017 kg/m² sec½) and the A4 casein-based specimen(0.0069 kg/m² sec½) displayed half Wa (0.0117 kg/m² sec½). Furthermore, both were twice as vapour Permeable (μ=5.77) as their relevant referenced specimens (μ=12-14). Regarding the second, further research in specimens performance in adhesion, durability, thermal conductivity, reaction to fire following the BS EN 15824:2009 guidelines for renders based on organic binder, will be conducted to prove the product market applicability. Also their exposure in real weather conditions could further verify the above. Assessing Wa and Vp results, clay-based specimens with polymers show potential as alternatives to external lime render. They combine notably higher water proofing capacity, breathability and minimum carbon footprint. These properties are primarily needed to protect energy efficiency of buildings, either a) in Historic energy restoration of porous structures, b) in existing stock renovations, or offer high sealing and VP in flood-prone areas.

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Effects of Weather Exposure on Solar Reflectance of External Paintings

Lucila Chebel Labaki[1], Edna Figueiredo[1], Adriana Petito de Almeida Silva Castro[1], Rosana Maria Caram[2]

[1]State University of Campinas, Department of Architecture and Building, Campinas (SP), Brazil, lucila@fec.unicamp,br, earq@terra.com.br, dripasc@uol.com.br
[2]University of São Paulo, Department of Artchitecture, São Carlos (SP), Brazil, rcaram@sc.usp.br

Abstract: Nowadays, there is a great variety of paintings' colours, available in the construction market, which greatly influence architectural projects. One may observe that, in a large number of buildings, the external painting is one of the most exposed elements to solar radiation, being responsible for a great deal of heat flow, which is transferred to and around the building. The influence of the external colour in the thermal performance of buildings has been extensively researched in many countries, as well as in Brazil, by using spectrophotometer analysis in recently painted tile samples, but there are few studies about the effect of weather exposure on these paintings. The analysis presented in this paper was carried with 2X2 cm samples of tiles painted with different painting colours, which were exposed to weather conditions for two years, by using a spectrophotometer with integrated sphere. in The analyses were carried out for several intervals of sun exposure in order to check the discolouring that each one went through along the period of two years, every two months. The superficial temperatures on a masonry surface painted with the same colours used in the samples and in the same intervals of time were simultaneously measured using an infrared thermometer. The results allowed a comparison of the two different methods of analyses showing the differences in behaviour among the different painting colours, not only in the visible range, but also for the near infrared, which gives an insight on important parameters which can contribute to improve studies about thermoenergetic performance and thermal comfort in buildings.

Keywords: colour reflectance, spectrophotometric analysis, environmental comfort

Introduction

Solar radiation directly influences indoor climate, human comfort and energy demand in buildings. When radiation reaches a building, the energy is partly absorbed and partly reflected. The heat gains through opaque surfaces due to solar radiation exert a great influence on the thermal comfort conditions of the internal environment (SEKER; TAVIL, 1996). In most of the buildings, the exterior painting is one of the elements most exposed to solar radiation, being responsible for part of the heat flow transferred to the building and its surroundings.

Solar heat gain is mainly defined by the reflectance of external surfaces as determined by their colours. Hence the importance of knowledge of the reflectance of painting colours most used in external paint.

Several researches have highlighted the exterior colour as a determining element that influences the amount of radiation absorbed or reflected by the construction materials, especially in hot and dry climates, making the choice of the colour extremely important in the construction process.

Light surfaces are not always indicative of high reflectance, since the reflectance of the materials depends not only on their reflection in the visible region, but also on their reflectance in the infrared region. Exposure to weather tends to decrease the reflectance of light materials and increase the reflectance of darker materials. Studies that monitored the effects of aging on ten roofs in California found that the reflectance of materials decreased by approximately 15% in the first year of use (Bretz, Akbari, 1997).

The use of high reflectance coatings can contribute to the reduction of surface temperatures. Prior to the application of a coating at a specific site, a complete study should be carried out to estimate the impact of such reflective surfaces on the microclimate, avoiding heat gains (Synnefa et al, 2005).

Alchapar et al (2013) studied solutions for urban spaces in order to mitigate the impact of Urban Heat Islands. It was considered that solar reflectance of the building envelope tends to change with time due to outdoors conditions and dirt accumulation. For a period of two years they measured thermo-physical behaviour of 80 textured coatings for facades on two compositions: acrylic and cement, with colours, textures and finishes spread locally to the vertical resolution of the urban envelopes. The results showed that 35% of acrylic coatings decrease their ability to mitigate the effects of heat island, while 98% of the cementitious ones maintained or increased their mitigation capacity. Coelho et al (2017) verified that the natural aging processes of asbestos cement tiles aged between 28 days and 36 months considerably alter the absorption and thermal performance over the lifetime of a building.

In this work the effect of solar radiation on external painted surfaces with several colours exposed to climatic conditions was studied, in order to verify the influence of the aging of the paints on the values of reflectance to solar radiation.

Methods

In this work, the adopted methods are separated in two stages: laboratory and field work, for a 2 years period. The results in laboratories express reflectance values by wavelength, in the range of 300 to 2000 nm, while the field measurements express the surface temperature of the wall.

For laboratory measurements, 25mm x 25mm cement pellets were prepared. After drying they were coated with spackling, to obtain samples with smooth surfaces, in order to reduce the maximum possible the roughness effect in the results of reflectance measurements. The samples were then coated with 3 coats of acrylic latex paintings in 10 different colours. This shape of the tablets suits well to the spectrophotometer support, allowing better fixation and ensuring stability when handling the device. The samples were fixed to the wall vertically, in order to obtain results closer to the real surface.

When using the spectrophotometric technique, the samples were analysed in several stages of Sun exposure, in order to verify the influence of the colour fading over time in relation to the reflectance, in the different regions of the solar spectrum. Samples were taken for analysis for 2 years at intervals of 6 months.

The reflectance values were obtained by the area integration method, by using the graphs obtained in the measurement. Initially the area relative to the measurement of a reference sample was calculated with an approximate reflection of 100%. Then the integrated area below the specular reflection curve of each sample was calculated. The results for each sample were obtained for the desired intervals: Ultraviolet (290 to 380nm), Visible (382 to 780nm), Infrared (782 to 2000) as well as to the whole solar spectrum.

Simultaneously, in order to verify the behaviour of the paintings in real weather conditions, a panel with ten spaces in the size of 40x40cm was also prepared on a masonry surface north oriented. Each space was painted in one colour, the same colour as the painting used in the laboratory samples. In this panel, the colours behaviour was accompanied by measurements of the surface temperature performed at various times of the day and also at different stages of exposure to time. For this stage of the work an infrared thermometer was used.

Colour surface temperature measurements were also taken at six-month intervals, however, to obtain a more accurate result, the temperature was measured at various times of the day (9h, 12h, 16h; 7:00 p.m.), for three consecutive days and always on sunny days. By means of the measurements realized in the three days an average of the temperature values was obtained for each hour. The measurements were performed in five steps: freshly applied paints and after 6, 12, 18 and 24 months, considering exposure to time.

Results

Results for the laboratory measured reflectances

Figures 1 to 5 show the obtained graphs for each colour, showing the spectral reflectance differences that occurred during the various periods in which the samples were exposed to the climatic conditions.

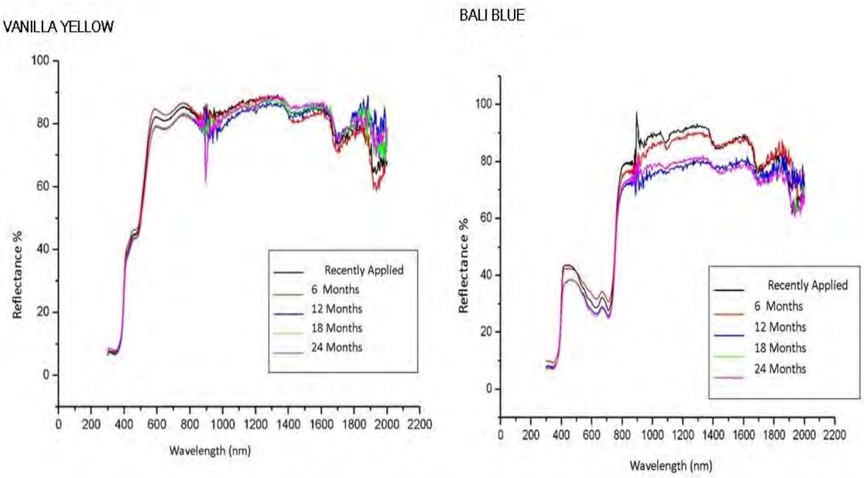

Figure 1. Reflectance curve yellow vanilla color and blue bali

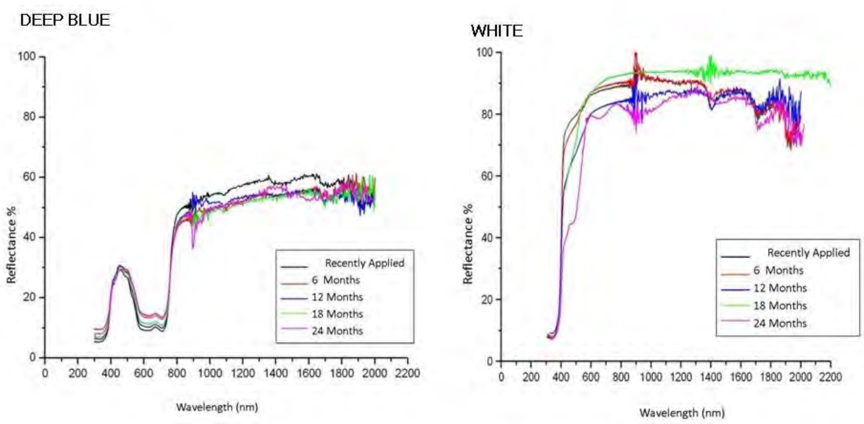

Figure 2. Reflectance curve yellow deep blue and white

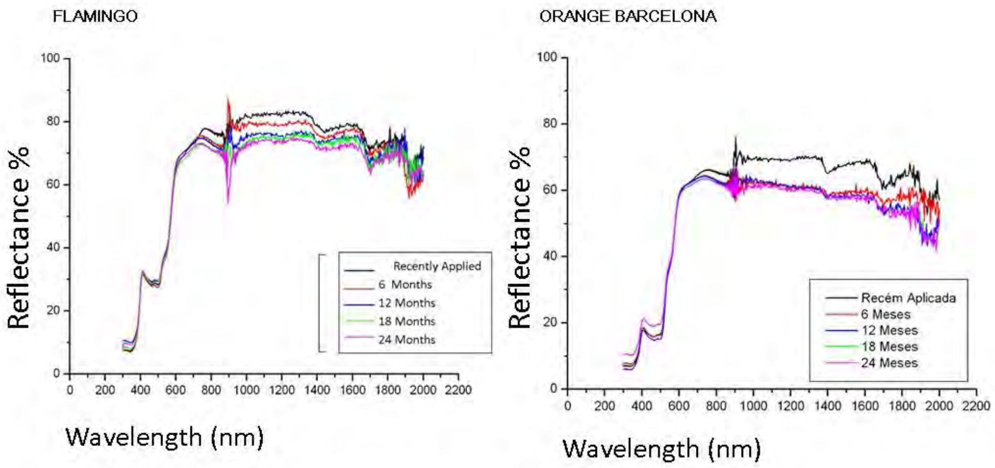

Figure 3. Reflectance curve flamingo color and orange barcelona

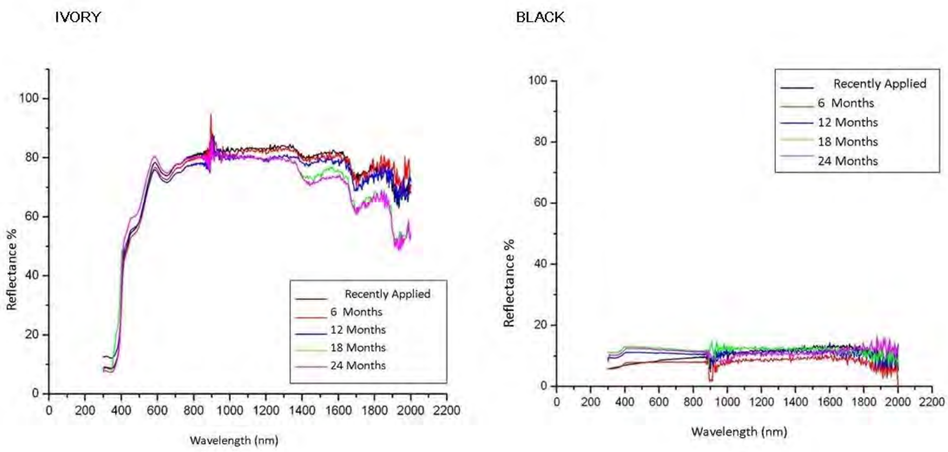

Figure 4. Reflectance curve ivory color and black

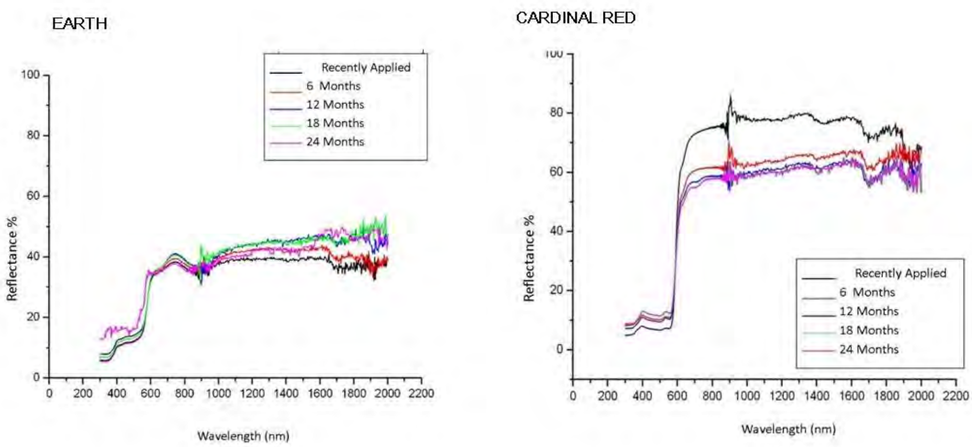

Figure 5. Reflectance earth color and cardinal red

By means of the results obtained, a comparison was made between the reflectance of the samples and the values obtained in the verification of the behaviour of the paints under real conditions through the surface temperature, aiming to obtain parameters that can identify how much the fading of the paints can influence in the values of solar reflectance.

Table 1. Reflectance of paints recently applied

COLOR	REFLECTANCE% (PAINTS RECENTLY APPLIED)			
	UV	VIS	IR	Total
White	8	80	86	81
Vanilla Yellow	8	67	81	75
Ivory	9	68	79	73
Bali Blue	8	36	84	68
Flamingo	8	51	77	68
Cardinal Red	6	36	75	63
Orange Barcelona	7	42	66	58
Deep Blue	6	17	56	44
Earth	8	25	37	33
Black	6	8	10	10

Table 2. Reflectance after 24 months

COLOR	REFLECTANCE % AFTER24 MONTHS			
	UV	VIS	IN	TOTAL
White	8	65	82	74
Vanilla Yellow	8	66	81	74
Ivory	8	66	72	69
Flamingo	9	51	70	63
Bali Blue	8	32	75	62
Orange Barcelona	10	43	56	51
Cardinal Red	9	31	59	50
Deep Blue	9	20	52	42
Earth	12	27	44	37
Black	10	12	11	11

Table 1 shows the reflectance values for the ultraviolet, visible and infrared radiation, as well as the values of the total reflectance for the samples painted with the newly applied paintings as well as the total reflectance of the painted samples that were exposed to the weather for 24 months. The values of the total reflectance are displayed in descending order.

Table 3. Total Reflectance

COLOR	TOTAL REFLECTANCE %				
	Recently Applied	After 6 M	After 12M	After 18M	After 24M
White	81	81	78	75	74
Vanilla Yellow	75	74	74	74	74
Ivory	73	72	71	69	69
Bali Blue	69	69	63	62	62
Flamingo	68	66	65	63	63
Cardinal Red	63	54	54	51	50
Orange Barcelona	58	53	52	51	51
Deep Blue	44	43	42	42	42
Earth	33	34	37	38	37
Black	8	10	10	11	11

Table 3. Total Reflectance

COLOR	TOTAL REFLECTANCE %				
	Recently Applied	After 6 M	After 12M	After 18M	After 24M
White	81	81	78	75	74
Vanilla Yellow	75	74	74	74	74
Ivory	73	72	71	69	69
Bali Blue	69	69	63	62	62
Flamingo	68	66	65	63	63
Cardinal Red	63	54	54	51	50
Orange Barcelona	58	53	52	51	51
Deep Blue	44	43	42	42	42
Earth	33	34	37	38	37
Black	8	10	10	11	11

Table 3 shows the difference between the total reflectance of the painted samples obtained for the 5 measurement periods; the reflectance values of the newly applied paints are displayed in descending order.

Results for surface temperature throughout the day

Table 4 shows the average values of the measured temperatures on the wall with the newly applied paintings. Table 5 presents the values of the measured temperatures in the wall with the exposed paints in the period of 24 months; the average temperature is displayed in ascending order.

Table 4. Recently applied

Color	9H	12H	16H	19H	Average Temperature
White	31,2	31,8	31,6	27,8	31,5
Vanilla Yellow	35,3	35,7	35,3	27,6	35,4
Ivory	35,3	37,7	35,3	28,7	36,1
Bali Blue	37,9	38,6	39,9	28,2	38,8
Flamingo	38,8	40,1	39,6	34,9	39,5
Orange Barcelona	38,8	39,1	44,2	39,8	40,7
Cardinal Red	38,9	41,1	42,5	36,1	40,8
Deep Blue	38,8	39,6	44,3	31,2	40,9
Earth	42,9	44,2	48,7	34,7	42,2
Black	43,8	48,5	50,8	39,4	47,7

Table 5. After 24 months

Color	9H	12H	16H	19H	Average Temperature
White	25,2	31,2	34,7	28,6	30,3
Flamingo	25,5	33,8	35,6	29,3	31,6
Ivory	25,3	34,7	35,4	29,4	31,8
Vanilla Yellow	27,5	35,8	35,9	28,9	33,0
Bali Blue	26,4	38,7	38,9	32,6	34,6
Orange Barcelona	26,6	41,8	42,1	32,6	36,8
Deep Blue	29,4	40,3	41,2	34,1	36,9
Cardinal Red	29,6	41,2	42,8	31,2	37,8
Black	34,9	41,8	41,2	35,7	39,3
Earth	29,2	44,2	46,7	34,7	40,0

Conclusion

Results for the total reflectance show that the majority of the colours considered as light and medium, in the course of 24 months exposed to weather, had their reflectance values decreased, when compared to the initial values. For the white colour, a great difference in the values of total reflectance is observed (81% for the newly applied paint and 74% after 24 months exposed to weather). Dark colours such as Black and Earth over time had their values increased.

The Red Cardinal and Orange Barcelona, considered as medium colours, showed the biggest differences in relation to the initial values and after 24 months exposure to weather. As for the Red Cardinal, its initial reflectance was 63% and after 24 months exposed to the sun reached 50%, with the biggest difference occurring in the first 12 months. For Orange Barcelona, its initial reflectance was 58% and after 24 months, it diminished to 51%, with the biggest difference occurring in the first 6 months exposure.

The results showed that the light colours presented higher reflections in all regions of the spectrum.

During the 24 months period, it was confirmed that the colours that reflect more in the visible are the same ones that reflect more in the infrared and in the UV, being, therefore, those that present greater total reflections.

In the visible region, the light colours showed higher reflections and, over time, these were decreasing. It is valid to assume that the effect of accumulation of the deposited dirt over time is quite significant for the light colours, to the point of significantly decreasing the reflectance.

In relation to dark colours, over time their reflections increased, because even with the dirt accumulation the surface temperature values diminished due to colour fading, showing behaviour similar to the tablets: the effect of dark colour fading exceeded the cumulative effect of impurities and dirt.

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Use of a whole building heat and moisture transfer building simulation tool to evaluate moisture buffering capacity of clay plasters in hot-humid climates

Shaghayegh Mohammad[1], Stephen Lo[1]

Department of Architecture & Civil Engineering, University of Bath, U.K., s.mohammad@bath.ac.uk

Abstract: Studies on hygrothermal properties of materials to passively moderate indoor humidity levels has in cold-moderate climates conclude that it helps improve Indoor Air Quality and reduce auxiliary energy loads. This research uses a validated whole building **H**eat **A**nd **M**oisture transfer energy simulation tool (WUFI Plus) to study the effect of a selected hygroscopic clay plaster on indoor environment in hot-humid climatic condition. A reference scenario was defined with use of gypsum plaster as the common wall finishing. Results indicate that clay can help buffer indoor RH especially when high indoor RHs happen. However, the effect on indoor temperatures is negligible. Results also indicate the importance of taking moisture into account in building energy calculations.

Keywords: humidity, mass transfer, modelling, indoor air quality, hygroscopic materials.

Introduction

The study of the moisture buffering capacity of materials has been the subject of renewed interest in the last decade (Rode et al., 2008). This capacity, known as the hygroscopic behaviour of a material, is defined as the change in a material's physical properties as a result of the simultaneous absorption, storage and release of both heat and moisture (Hall & Casey, 2012). When additional moisture is generated in indoor spaces, hygroscopic materials act as a buffer, absorbing and storing it; when the humidity source is removed, they release this moisture back into the environment. This capacity can be used as a passive way of controlling the diurnal amplitude of indoor relative humidity (RH) and keep it within the range for thermal comfort. Passive control does not require energy input or human intervention, so it represents a more resilient and sustainable option in many situations (Woloszyn et al., 2009). Removal of humidity also removes latent heat, thus reducing cooling loads.

It should be noted that adsorption/desorption of moisture by materials also affects their heat transfer properties because the basic properties of materials, such as thermal conductivity and density change with moisture content (Hall & Casey, 2012). This adds complexity to building energy modelling when attempting to simulate moisture transfer because a more dynamic approach is needed to take into account the mutual influences of heat and moisture on one another.

Existing studies describe the hygroscopic behaviour of materials and their effect on indoor climate, heat transfer, energy consumption and the durability of construction assemblies mostly in the context of cold and temperate climates of north European countries specifically Scandinavian countries as well as north Americans (Simonson et al., 2004, Woloszyn et al., 2009, Yang et al., 2012, Kalamees et al., 2009, Lengsfeld et al., 2005). The research described in this paper adopts the same level of robustness for a more challenging climate to support building practitioners in those areas to apply this concept when designing buildings. The study takes place in a hot-humid climate with small amount of precipitation and high rate of cooling load during summer which is known to be difficult to provide thermal comfort for occupants. Controlling indoor RH is more important in these climates as combination of high temperature and RH limits boundaries of comfort.

WUFI Plus has been selected to study effects of applying a hygrothermal material (clay plaster) on the diurnal indoor fluctuation of RH and the impact on comfort and well-being of occupants. This software is a whole building Heat And Moisture (HAM) transfer energy simulation based on the hygrothermal simulation model for building envelopes developed by Künzel (Künzel, 1995) and has been used and validated against experimental data in different studies (Lengsfeld et al., 2007, Antretter et al., 2011).

Indoor humidity and comfort

Indoor Air Quality (IAQ) is closely linked to indoor RH levels (Arundel et al., 1986). Low indoor RH levels result in dryness of the skin, mucous membranes, sensory irritation of the eyes and upper airways. High RH levels may result in material deterioration and mould growth (Padfield, 1998, Kwiatkowski et al. 2011, Woloszyn et al. 2009). Moreover, in most indoor environments inhalation of air will cause a cooling of the mucous membranes in the upper respiratory tract, which contributes both to the perception of thermal environment and to the perceived air quality (Toftum et al.,1997). At high air temperatures and humidities, respiratory cooling is reduced resulting in air being perceived as stuffy and uncomfortable. In addition, at high RH levels the rate of transpiration from the skin is decreased, hence reducing the evaporative cooling effect caused by sweating of the human body. Therefore, different parameters need to be accounted for when defining the optimum range for indoor RH (Figure 1). As illustrated the indoor humidity should be kept below 60% RH to avoid the growth of fungi and mites and above 40% RH to reduce respiratory infections (Arundel et al., 1986). In terms of thermal comfort, ASHRAE standard 55-2010 defines the upper limits of RH between 55 and 80% depending on the temperature. However, no limit has been defined for lower limit of indoor RH (ASHRAE, 2010).

Simonson et al. (2004) investigated the effect of hygroscopic wooden panelling on indoor humidity conditions in three Canadian cities using a numerical model. Their result indicated the importance of hygroscopic materials specifically during the humid and cool seasons.

Hall and Casey (2012) studied HVAC energy consumption in a room located in Leicestershire, UK, constructed with stabilised rammed earth and compared the results with non-hygroscopic and less-hygroscopic cases. The results indicated that when used in conjunction with the HVAC system, there was a significant reduction in humidification and dehumidification energy demand when compared to the conventional wall materials. However, energy saving was less when HVAC unit was used intermittently due to the extra load imposed on the HVAC unit to remove the moisture being absorbed by the SRE walls when the system had been turned off.

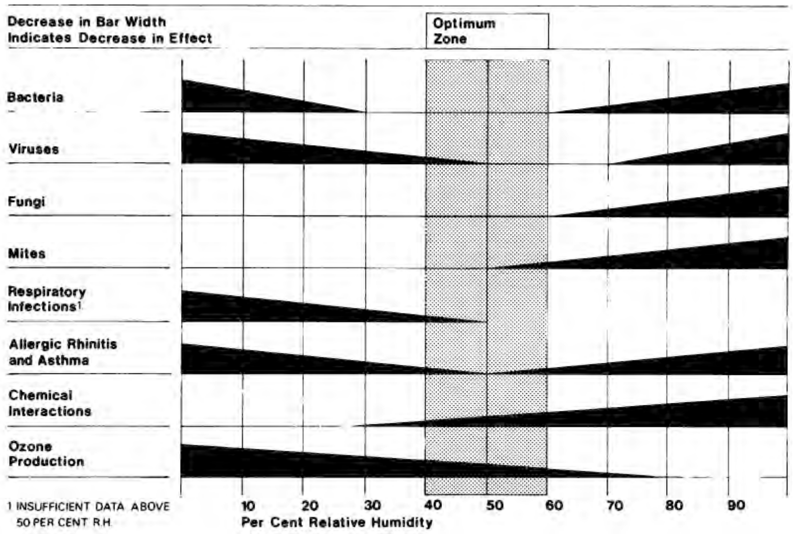

Figure 1: Health and IAQ parameters are affected by indoor RH (Arundel et al., 1986)

Kunzel et al. (2005) studied the hygrothermal performance of a plastered room against a room covered with aluminium sheets in hot and humid climate of Bangkok and Miami using WUFI Plus. Their result indicates that indoor RH in plastered room stays well below 80% hence reducing the risk of mould growth.

Qin et al. (2011) investigated the effect of hygrothermal transfer through building envelopes on indoor air humidity and energy consumption in moderate, hot-humid and hot-dry climates. They concluded that taking moisture into account has a more distinct effect on indoor humidity in hot-humid and moderate climate than the hot-dry one. The use of suitable hygroscopic materials reduces energy consumption with the most promising results coming from buildings located in hot-humid climates. The peak cooling demand is 12% and 33% lower in moderate and hot-humid climate respectfully.

Clay Plasters as an alternative construction material

For several years, earth construction was abandoned in favour of concrete in developed economies. In recent years, following the global awareness towards more sustainable use of natural resources and the negative environmental impacts of conventional construction materials (Wang et al., 2014), earth-based products, plasters being one of them, are becoming popular again (Faria et al., 2016). Besides its low embodied energy and recyclability, earth is known to be a natural humidity regulator helping in improving IAQ and comfort inside buildings (Laborel et al., 2016); a capability that is related to the hygrothermal properties of this material.

It should be noted that although the soil used for earth construction cannot be regarded as a renewable resource, its extraction is much less energy-intensive than the extraction of raw materials for conventional masonry products, as the soil used for earth construction is located immediately below the organic layer of the soil (Torgal & Jalali, 2011).

Building energy simulation tools

When building energy simulation tools started to be used in 1960s, they were mostly concerned with modelling the thermal performance of the building and interaction of moisture was mostly neglected (Hong et al., 2000). IEA Annex 41 project, launched in 2004, was the first attempt for simulation tools to take into account moisture in handling the whole building performance (Woloszyn and Rode, 2008). Today there are different numerical models that evaluate moisture balance in an enclosed space or predict indoor humidity levels. They differ in the way that they deal with the moisture storage process within the material and can be categorised under two general classifications (Janssens & de Paepe, 2005).

For the first group the main focus is on predicting temperature profiles and energy demands of each space, so two types of simplified approach are taken to account for water vapour exchange with surrounding materials; firstly, the effective capacitance, assumes that room and material humidity are always the same, therefore one single room moisture capacity is considered to include both parameters. Secondly the Effective Moisture Penetration Depth model, differentiates between the room humidity and a representative material humidity, so a single equivalent volume representation of the average moisture transfer and storage in the material is considered to represent the material. The second group of indoor humidity models has been produced by combining thermal building simulation with models for Heat And Moisture transfer in building components (Janssens & de Paepe, 2005). A HAM model takes moisture sources and sinks inside a component, capillary action, diffusion and vapour adsorption and desorption as well as the well-known thermal parameters into count (Antretter et al., 2011). It is also capable of defining the exchange of water vapour (transfer and storage) between the room air and the surrounding enclosure (Janssens & de Paepe, 2005). Therefore, interactions between the heat transfer in the walls and the moisture balance in the enclosure are accurately described in HAM models. HAM models also incorporate the dependency of thermal material properties on moisture content.

Figure 2: BESTEST building

Methodology

The IEA BESTEST building (Figure 2), also referenced in ASHRAE Standard 140, was used in this study allowing simple comparison between results of different simulations. This model was devised in the WufiPlus software and different scenarios were defined to study the potential benefit of applying clay plaster to moderate indoor RH (hygrothermal case). The reference simulation was defined by applying gypsum plaster on internal surfaces (non-hygrothermal case). The weather data used for all simulations is for a port called Lengeh in south of Iran which features hot and humid climate. The southern coastal region of iran has the highest rate of energy consumption in the country.

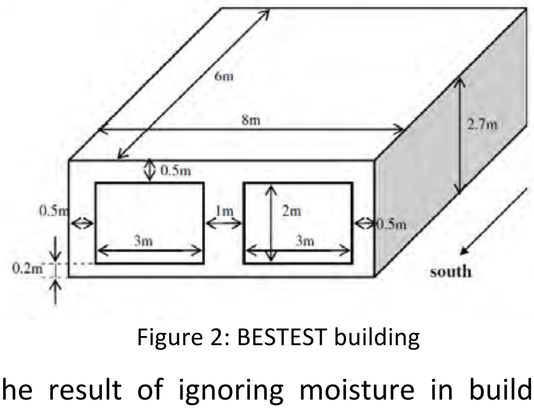

Figure 2: BESTEST building

In first scenario, the result of ignoring moisture in building simulation models is discussed by running an only heat transfer simulation as well as a heat and moisture transfer simulation in Wufi Plus. In this software there is an option which allows the user to include or exclude moisture in calculations. A gypsum plastered solid brick construction was modelled as well as a construction plastered with clay to compare their effect on indoor RH. Air infiltration rate was 0.5 air change per hour, no internal gains were added to the simulation and windows were closed i.e. no natural ventilation.

In a second scenario, two types of construction blocks i.e. Autoclaved Aerated Concrete and solid clay brick were modelled in Wufi to study the role of substrate in hygric and thermal calculations and indoor RH. These blocks are commonly used in Iran. In this scenario it was decided to remove all glazed surfaces i.e. all surfaces were opaque to eliminate the effect of solar gains and have a pure evaluation of thermal and hygric behaviour of materials themselves. A third scenario was also defined with night time ventilation applied during 6 months of the year from May to the end of October from 23.00 pm to 7.00 am to see if natural ventilation reduces the potential benefit of hygroscopic materials in moderating indoor environment. In all simulations all surfaces of the building including floor and roof were made of the same construction assembly and were in contact with the same environment being outdoor air (even for the floor slab) to facilitate interpreting the result. Simulation scenarios have been summarized in table 1.

Table 1: Simulation scenarios

Scenario	Construction		Infiltration
1	- Solid clay brick + Gypsum plaster - Solid clay brick + Clay plaster	-No NV - No internal gains	0.5 [ac/h]
2	- Solid clay brick + Gypsum plaster - Solid clay brick + Clay plaster - AAC block + Gypsum plaster - AAC block + Clay plaster	-No NV - No internal gains - No windows	0.5 [ac/h]
3	- Solid clay brick + Gypsum plaster - Solid clay brick + Clay plaster	-Night time NV 8 lit/s From 23:00-7:00 May to November - No internal gains	0.5 [ac/h]

Results and discussion

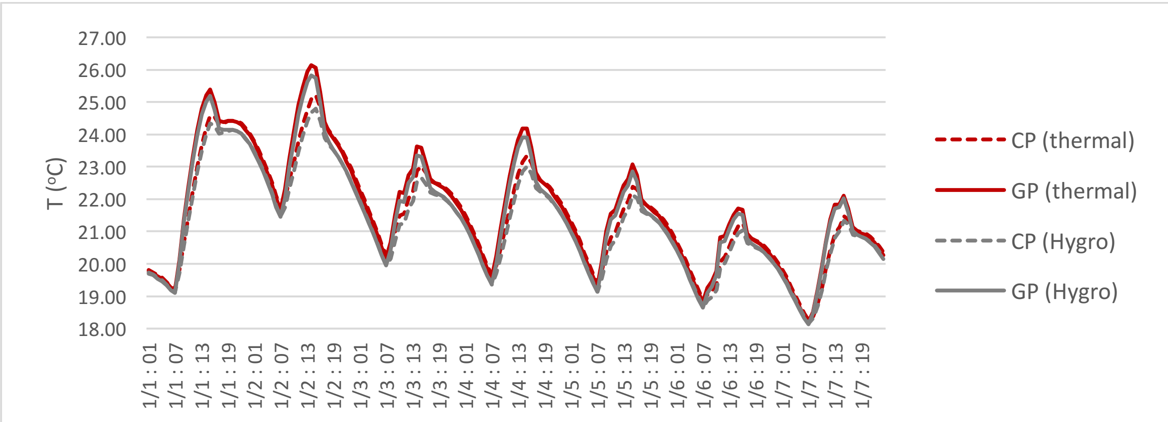

Figure 3: Indoor temperature derived from thermal & hygrothermal simulations, 1-8 January
GP: Gypsum Plaster CP: Clay Plaster

Scenario 1**:** In order to illustrate the importance of taking moisture into account in energy simulations, a simulation was run with only thermal simulation applied and the result was plotted against the result of a whole HAM transfer simulation during one week in winter. As can be seen on figure 3, there is not much difference in indoor temperature when moisture is ignored. However, the variation in indoor RH is distinct (figure 4 & 5). The difference in result of hygrothermal and thermal simulation is even more distinct when applying a hygrothermal material i.e. clay plaster as even the pattern of fluctuations is different. This difference in calculation results leads to a wrong estimation of heating, cooling, de/humidifying demands of the building and a poor design which does not meet the requirements of the building occupants.

This result also indicates that indoor RH is more stable when Clay Plaster (CP) is applied especially in winter when higher indoor RH (above 60%) is prevalent. However when moderate RH is observed in indoor environment (45-50%), the effect is not distinct. In terms of indoor temperature the performance of both constructions is quite similar despite Brick + GP having lower U-value. Construction covered with clay plaster experience slightly less fluctuation in indoor temperature in winter and in summer a time lag is observed in indoor temperature peak due to higher heat capacity of clay compared to gypsum.

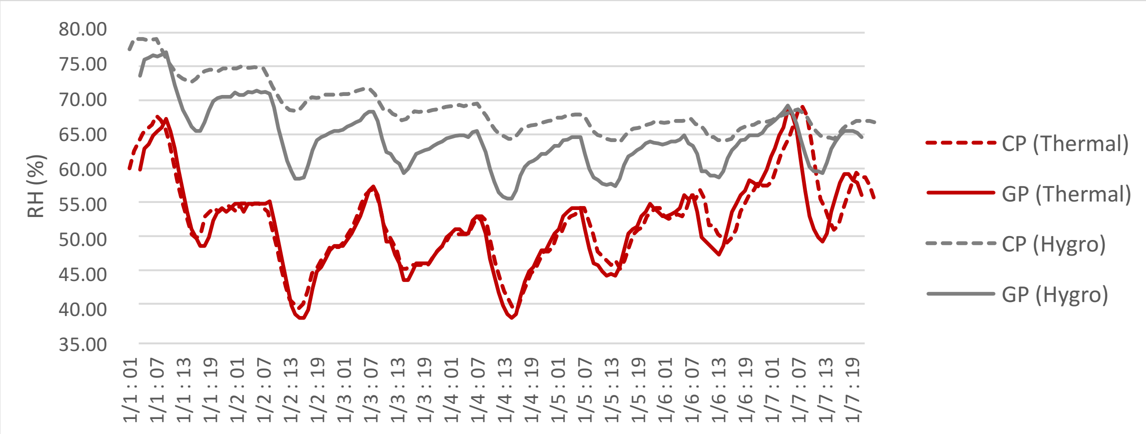

Figure 4: Indoor RH derived from thermal & hygrothermal simulations, 1-8 January
GP: Gypsum Plaster CP: Clay Plaster

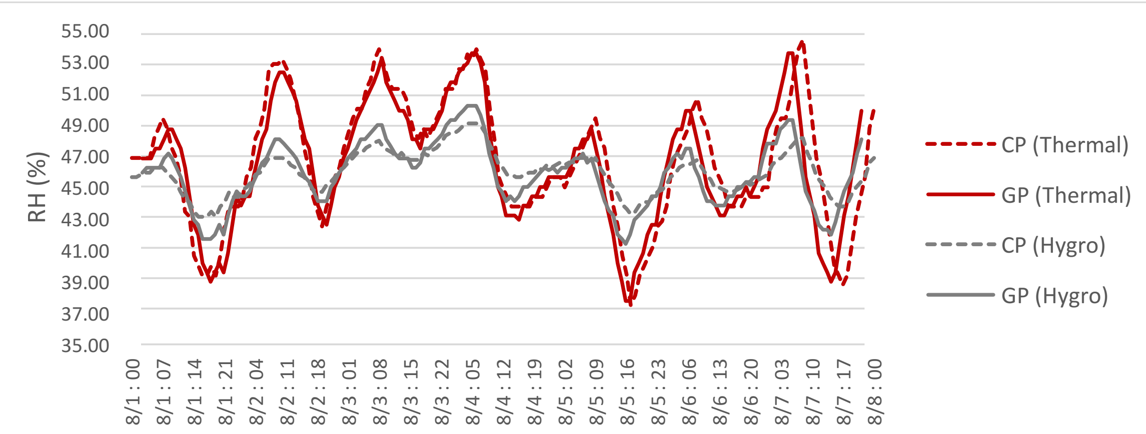

Figure 5: Indoor RH derived from thermal & hygrothermal simulations, 1-8 August
GP: Gypsum Plaster CP: Clay Plaster

Scenario 2: In order to have a clear evaluation on hygrothermal performance of building fabric, it was decided to remove all glazing in one simulation. This eliminates the effect of solar gains and makes it possible to interpret the result solely based on materials performance. As can be seen on figure 6, constructions with same block type result in similar indoor temperature. However when it comes to indoor RH, internal finishing becomes the influential factor and constructions with same plaster type show more similar performances in dealing with moisture and resulting indoor RH. Therefore, the role of substrate in governing indoor RH is negligible. An appropriate combination of the construction block (substrate) along with the finishing material (plaster) can improve building fabric performance.

Scenario 3: In final scenario night time ventilation was applied to study materials performance in a more realistic situation. Night time ventilation reduces indoor temperature resulting in indoor RH peaks. Same as in the first scenario clay plaster helps in humidity buffering and especially in avoiding low RH levels. This strategy needs to be combined with a HVAC unit to give some actual data on energy use and potential energy saving.

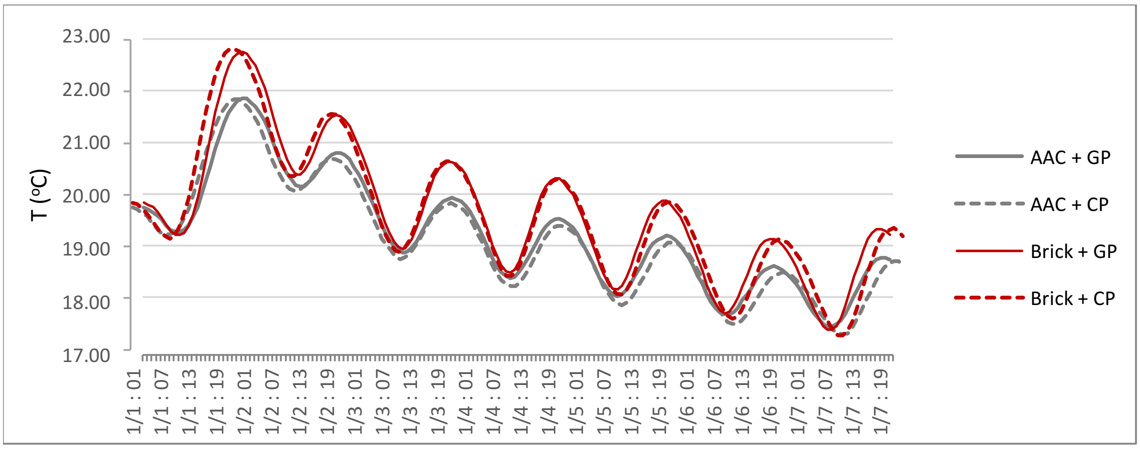

Figure 6: Indoor temperature in non-glazed construction, 1-8 January
GP: Gypsum Plaster CP: Clay Plaster

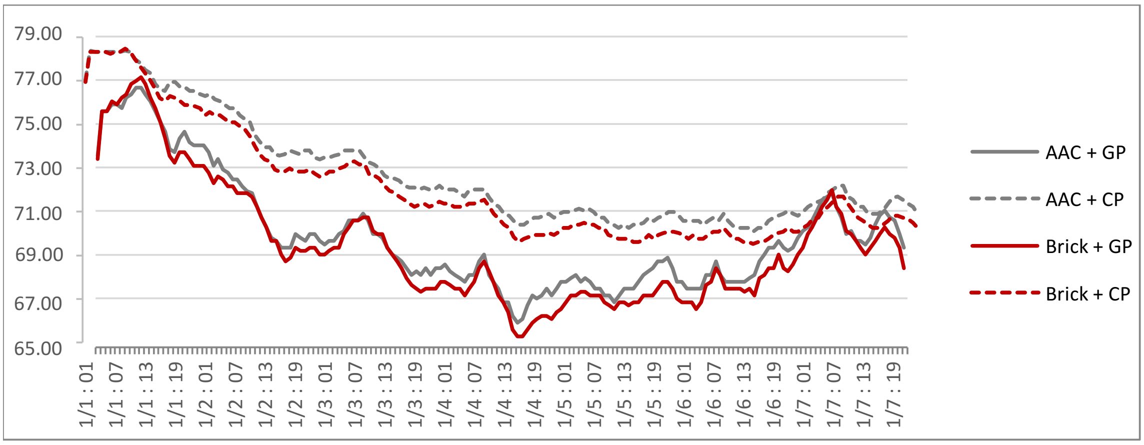

Figure 7: Indoor RH in non-glazed construction, 1-8 January
GP: Gypsum Plaster CP: Clay Plaster

Conclusion

The importance of taking moisture into account in energy simulation models and the potential benefit of the use of hygroscopic materials in moderating indoor environment in a hot and humid climate were studied in this research. A whole building HAM tool, WUFI Plus, was used to model a simple geometry comparing performance of clay plaster as a hygroscopic material with gypsum plaster. Results show that ignoring moisture in building performance modelling has a distinct effect on predicted indoor RH levels especially when a hygroscopic material such as clay plaster is applied.
Results also indicate that in a free running building clay plaster buffers indoor RH fluctuations to some extent, however it has a more distinct effect in higher indoor RHs (above 60%) which happens mostly during winter. Adding plant-based aggregates to clay plaster can help increasing moisture adsorption in lower RH levels. A more sophisticated simulation scenario involving mechanical systems can help studying the potential benefits of hygroscopic materials when mechanical system are in use.

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Experimental characterization of an agromaterial based on Typha aggregates and clay

I Niang[12]*, C. Maalouf[1], T. Moussa[1], A. Gacoin[1], N. El Wakil[1], M. Lachi[1], E Samin[3], T.H. Mai[1], S. Gaye[2]

[1] GRESPI, SFR Condorcet FR CNRS 3417, University of Reims Champagne Ardenne, 51687 Reims, Cedex 2, France
[2] University of Thiès, LME, BP 120, Thiès, Sénégal
[3] International Center for Earthen Construction, CS 12636, Grenoble, France
[*] Corresponding author; email: ibrahim.niang@univ-reims.fr ; ibrahimniang@hotmail.com

Abstract: Recently, the use of agromaterials in buildings is of great interest in order to improve energy efficiency and renewable energy in a sustainable development context. Some studies are conducted on tropical agro-resources such as Typha which grows abundantly in African west coast countries. In this work, an agromaterial composed of clay and Typha Australis aggregates is characterized in terms of mechanical, hygrothermal and acoustic properties. The Typha aggregates morphology and the binder amount are evaluated in order to determine their impact on the material behavior. For this, different formulations are tested. The first two formulations are of the same binder quantity (clay and tap water) but differ by the Typha aggregates cutting mode: one from longitudinal plant cut and the other from a transverse cut. However, the third formulation comprises an aggregate produced by cross-cutting with a greater binder amount. In the fourth formulation, designed for coating applications, the residues of two different aggregates are used. Mechanical tests are performed such as bending at four points and acoustic measurements including sound absorption. In addition, hygrothermal behavior is characterized by measuring the moisture buffering value. Results show a real impact of the Typha aggregates morphology and the binder amount on the material behavior.

Keywords: Typha Australis, clay, experimental characterization, mechanical properties, hygrothermal properties, acoustical properties.

Introduction

Construction and building industries are the two sectors responsible for 40% of energy consumption (Yan and Chouw 2013). The energy production, mostly of fossil origin, has increased the greenhouse gases emission which consequences are disastrous (climate change, deforestation, migration for economic reason). Building is one of the sectors responsible for excessive energy consumption leading to a high level of greenhouse gases emission (ADEME 2005). Therefore, there is a crucial need to minimize the environmental impact by reviewing the buildings design using the existing methods as for instance, HQE (Haute Qualité Environnementale) in France, LEED (Leadership in Energy and Environmental Design) in USA, and BREEAM (BRE Environmental Assessment Method) in UK. Architects(Niang 1986) and researchers(Gaye,S 2001) carried out studies to integrate bioclimatic architectural design and improve the thermal comfort of buildings using appropriate materials. Among the recommendations, these methods propose the use of biosourced materials as wood, hemp, and straw due their technical (Cerezo 2005), (Samri 2008),(Glé 2013), their environmental performance, and their permanent renewal as Typha Autralis. Typha Autralis is a plant which grows in hot climate especially in Senegal. However, it threatens the local ecosystem and constitutes a socio-economic danger for the invaded area (PNUD 2013). Thus, this plant must be valorized as a bio-based building material in association with an eco-friendly binder as clay. The review on mechanical, hygric, and acoustic properties of building materials derived from biomass (Cerezo 2005) (Millogo et al. 2014) (Dieye et al. 2017) (Diaw,A.S. et al 2016) (Diatta, M 2011) shows a good hygrothermal and acoustic performances but a low mechanical strength.

The present contribution presents an agromaterial based on Typha and clay. The material behavior dependency is analyzed with respect to the morphology and Typha aggregates amount. The first part presents the material and its physical characteristics. Then, the experimental methods are detailed followed by the results and the impact of the type and aggregates amount on the material behavior.

Materials

Typha

Typha australis is an herbaceous, monocotyledonous plant grown in hot climate countries especially in Senegal. Its height can reach 3.50 meters. It is composed of rhizomes, a stem surrounded by leaves, and a cob-fed blade that can contain between 20,000 and 700,000 seeds (Theuerkorn 2002) explaining its high reproductive capacity. In our study, Typha plants (figure 1) were harvested and transported from Senegal according to (ASN 2014). For this study, samples are prepared using two types of Typha aggregates: one from longitudinal cut and the second from transversal cut of the plant. Figure 2 illustrates the two aforementioned types of cut (L: longitudinal; T: transversal).

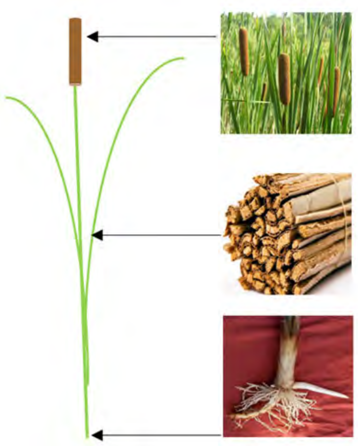

Figure 1 : Typha Australis plant

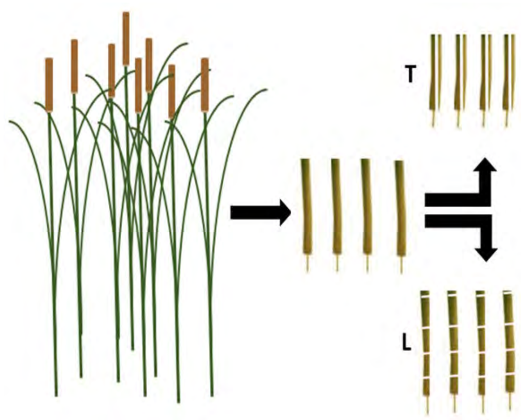

Figure 2 : Cutting strategy of Typha plants

Physical characteristics can be resumed as follows:

- Aggregates resulting from transversal cut (figure 3): this cutting mode maintains the internal structure of the plant characterized by a high porosity. The outer surface of the fiber is rough. The bulk density of the aggregates is about 55 kg/m^3;

- Aggregates resulting from longitudinal cut (figure 4): In this case, the aggregates are similar to chips with a low intra-particle porous structure and a smooth external wall. The bulk density is of 60 kg/m^3.

Figure 3 : Morphology of the transverse fraction of Typha

Figure 4 : Morphology of the longitudinal fraction of Typha

Clay

In this work, clay soil provided by "Thicky" in Thiès region in Senegal is used. Several tests such as granularity and plasticity were carried out to characterize this soil in order to examine if it is suitable as a building material. Figure 5 (Riveros Olmos 2016) shows the granulometric result and it appears that the clay is almost composed of 62% fine particles.

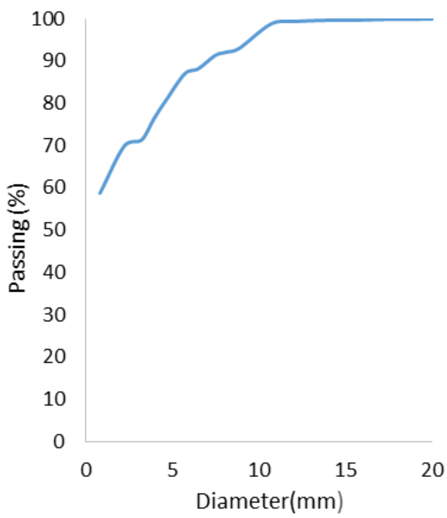

Figure 5: Thicky soil granulometric analysis

Materials formulation

Different formulations are prepared (tab 1) (Samin 2016) in order to estimate the influence of Typha aggregates morphology and the mass fraction on the behavior of this eco-material. The 1A and 2A present approximately the same amount of Typha aggregates but differ in the cutting mode. However, the 2B results from a transversal cut with a high proportion of water and clay.

Table 1 : Material characteristics

Formulation	Cutting type	Fraction content (%)	Density ($kg.m^{-3}$)	Standard deviation ($kg.m^{-3}$)
1A	Longitudinal	32	322,990	9,710
2A	Transversal	28	304,281	1,271
2B	Transversal	17	585,499	3,814

It can be seen that aggregates produced by longitudinal cut (1A) present the highest standard deviation value. Indeed, it should be noticed that they broke up quickly after the drying phase. This is due to the morphology of these particles. In fact, because of their low roughness, they adhere less to the binder.

Experimental characterisation

Four-point bending

Four-point bending tests are carried out using an Instron 8800 traction machine (Grove City, USA) (figure6) with a speed of 0.05 $mm.s^{-1}$. The maximum flexural strength is given as follows:

$$\sigma_{max} = \frac{3.F}{b.h} \quad (1),$$

with F is the applied stress(N), b the thickness (mm), and h the height (mm).

The samples (400 x 100 x $100mm^3$) are subjected to a bending force applied by an electromechanical press and perpendicular to the direction of aggregates orientation. The resulting displacement is then calculated by the measuring device.

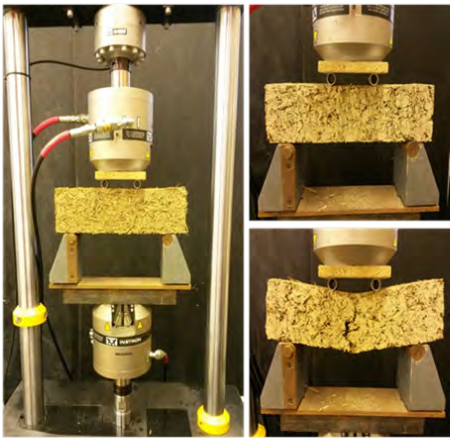

Figure 6 : Experimental device for bending test

Moisture buffering capacity

Moisture buffering value characterizes the ability of a material to dampen relative humidity variations. Based on a specific protocol (Rode 2005), it is defined as :

$$MBV = \frac{\Delta \mathrm{m}}{\mathrm{A.(HRhigh - HRlow)}} \ (2) \ ,$$

where Δm is the mass variation during the absorption or desorption phase (g), A is the exchange surface (m^2), HRHigh and HRLow are the high and low relative humidity during the cycle. It is expressed in g/m^2%RH. Samples of dimensions (100 x 100 x 50mm^3) (figure 7) are subjected to several dynamic sorption and desorption cycles during which the relative humidity is successively set at 75% for 8 hours then at 33% for 16 hours. Test is stopped when the mass variation during adsorption phase is less than 5%, on 3 consecutive days. A preliminary phase of mass stabilization is necessary where the samples are placed in a climatic chamber maintained at 23 ° C and 50% relative humidity.

Figure 7 : Sample for MBV test

Sound absorption coefficient

To evaluate acoustic performance of the studied agromaterial, sound absorption coefficient and transmission loss TL in the frequency ranged between 100 and 2000 Hz are measured. Sound absorption corresponds to the material ability to absorb the energy of a sound wave. The highest level of absorption is that of a material whose coefficient is close to 1(ISO 10534-2 1998). These tests are carried out with the Kundt AcoustiTube (Akustikforschung AFD1000 / AFD1200) (figure 8) which is a measurement method using samples of 10 cm diameter. The used measuring method is based on the use of three microphones (two upstream the sample, and a third downstream).

Figure 8 : Kundt's tube

Results

Flexural strength

Figure 9 shows the load versus displacement obtained for the flexural tests for each formulation 1A, 1B and 2B. The 2B formulations have an important ultimate load (near 900N) and a brittle failure to compare with 1A and 2A formulation. For 1A and 2A formulation the ultimate load is low (between 150 to 200 N) and the flexural test does not lead the failure of the agrocomposite, and induces a continuous increase of the displacement. This results show the influence of the binder ratio in the agrocomposite. Formula (1), make possible to plot the curve of the tensile stress for each formulation as a function of the density.

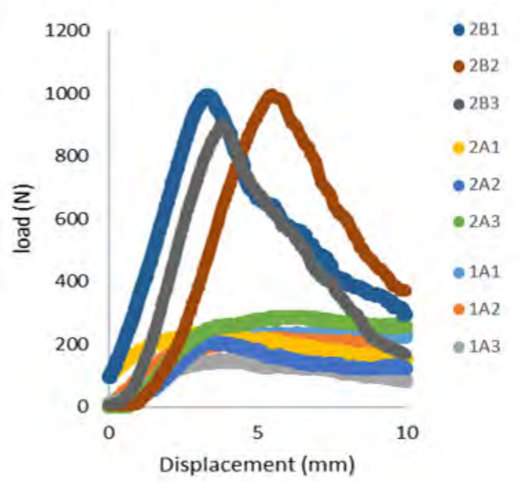

Figure 9 : Load versus displacement for each formulation

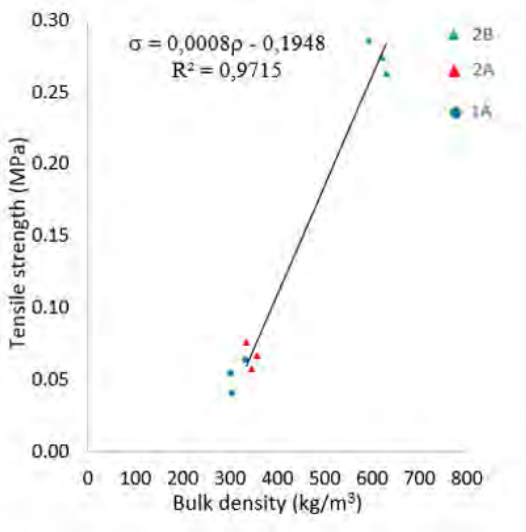

Figure 10: Tensile strength versus density of each formulation

Figure 10 shows that the formulation 2A has a better flexural strength (0.066 MPa) than the formulation 1A (0.054 MPa). Indeed, the section "Typha" in this paper show that transversal fraction of typha are more porous. The cohesion between the typha and clay allows a better transfer of the stresses on the matrix. Moreover, an increase in the binder amount significantly improves the tensile strength thanks to its greater stiffness (0.280MPa). Formula (2) shows the evolution of the maximum tensile stress as a function of the density for each formulations where aggregates are only derived from the transverse cutting of Typha:

$$\sigma = 0.0008\rho - 0.1948 \ (2)$$

Moisture buffering value

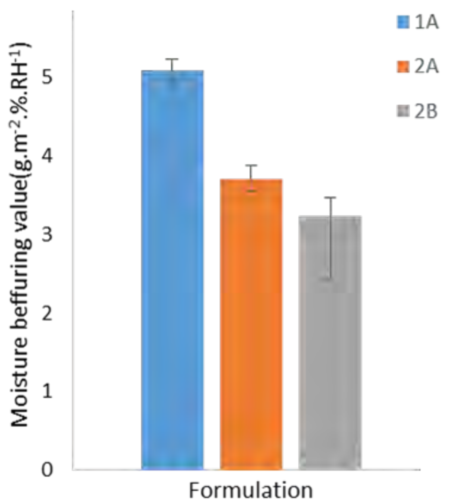

Figure 11 : Moisture buffering value

Figure 11 shows the moisture buffering values for the tested formulation. Values are ranged from 3.24 to 5.08 g.m^{-2} %.RH^{-1}. According to Rode classification, Typha-clay agromaterial can be classified as an excellent moisture regulator (MBV > 2). Measurements show that, at equivalent binder dosage, samples having aggregates from a transverse cut present a lower moisture buffering value (3.75 g.m^{-2} %.RH^{-1}) compared to those made by aggregates from a longitudinal cut (5.08 g.m^{-2}.% RH^{-1}). This could be explained by the porous structure of the longitudinal aggregates mainly composed of macropores which are able to adsorb and desorb water more than micropores presented in transversal fraction. It should also be noted that for the same type of aggregate, an amount of additional binder decreases the capacity of the moisture regulator material from 3.75 to 3. 24 g m^{-2}% RH^{-1}.

Sound absorption coefficient

Figure 12 shows the sound absorption coefficient as a function of frequency for the three formulations. It is found that the sound absorption coefficients for the two first formulations (1A and 2A) are low at low frequencies (60 to 500 Hz) then, they increase sharply with a maximum absorption level at frequencies between 1000 and 1250 Hz. For the 2B formulation, the absorption level is high compared to the first two formulations at low frequencies with a maximum level of 0.91. The acoustic absorption value increases to 0.91 for a frequency ranged between 500 and 900 Hz then decreases to 0.46. The 2A and 2B are more porous than the 1A formulation resulting in a high sound absorption coefficients.

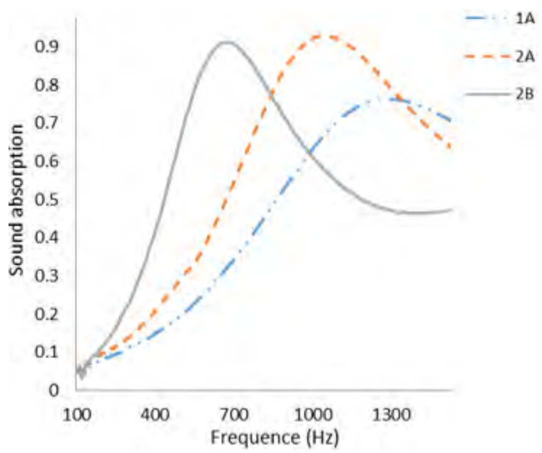

Figure 12: Sound absorption coefficient of each formulation

Conclusion

In this paper, a preliminary study on Typha-clay agromaterial was performed. Two strategies of Typha production were presented as well as their impact on the material behaviour. A first cutting mode consisting of fractioning the Typha's rod longitudinally and a second transversely. The results show that the flexural strength for a formulation composed of Typha cross-section is slightly better by 10%. This level of resistance is multiplied by 4 when the Typha portion in the mixture is divided by 2. Concerning the MBV, the longitudinal fraction improves moisture buffering by almost 35% (from 5.08 to 3.75 g.m^{-2}. %.RH^{-1}). However, for a Typha's transverse fraction, it decreases about 15%. Finally, acoustic tests show that the compositions whose granulate is the most porous (transverse cut) absorb the energy of the sound wave better with a coefficient close to 0.92. The decrease of the amount of transverse fraction makes it possible to maintain the maximum sound absorption level for medium frequencies.

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Criticality assessment of indium for thin-film photovoltaics in the context of sustainability goals for the German housing sector

Rosina Rieder[1], Sandra Krommes[1] and Werner Lang[2]

[1] Sustainable Engineering and Management, Faculty of Management and Engineering, Rosenheim University of Applied Sciences, Rosenheim, Germany, sem.wi@fh-rosenheim.de

[2] Institute of Energy Efficient and Sustainable Design and Building, Faculty of Civil, Geo and Environmental Engineering, Technical University of Munich, Arcisstr. 21, 80333 Munich, Germany

Abstract: In countries with large import dependencies, several studies on strategically important metals have classified raw materials as being critical by combining supply and vulnerability risks. In case of availability, the most critical raw materials are metallic ores and industrial minerals. Within the scope of developing resource efficient buildings, innovative building technologies, such as renewable energy systems, are becoming increasingly integral parts of buildings. Since critical raw materials are essential components in building technologies, they will also play an important role in the housing sector. In this context, it is crucial to consider how sustainability goals in the housing sector are affected by raw material criticality. This paper addresses supply and vulnerability risks of indium, which is contained in thin-film photovoltaics, in order to identify their impacts on future developments in the housing sector. Raw material availability is significantly influenced by the demand and supply of raw materials. To implement risk factors for a criticality assessment in sector-specific material flows, their impacts are analysed and modelled using a dynamic, macro-economic approach. Assuming different energy scenarios in the German housing sector up to 2050, the model reveals the raw material criticality by pointing out supply risks in order to derive recommendations.

Keywords: criticality, raw materials, thin-film photovoltaics, indium, system dynamics

Introduction

The housing sector plays an important role in reaching sustainability goals by resource efficiency improvement. The German strategy follows two objectives in the housing sector to reach a nearly climate-neutral state by 2050: (1) energy consumption reduction and (2) increasing renewable energies use (BMWi, 2015; Bürger, 2016). These plans require innovative technologies like cooling systems, photovoltaics or energy storage systems. Increasing requirements on building technologies lead to increasing needs of scarce resources like metals and industrial minerals. In this context it is crucial to consider if following sustainability goals in the housing sector creates problems of availability or environmental impacts induced by criticality of raw materials.

The availability of raw materials, which meet the needs and requirements of future technologies, is an important issue of technology-driven economies. Import dependencies on strategically important resources force affected economies to argue with risks created by concentrated resource availability. The assessment of raw materials criticality resulted in several studies within the last decades. Raw materials are classified as critical by risk indicators which can be categorized into supply risks, related to the availability of raw materials and vulnerability risks, related to the effects of shortages on the demand side. Affected raw materials are mainly metals and industrial minerals. (EU, 2014; Brandenburg et al., 2016; Marscheider-Weidemann et al., 2016)

Since critical raw materials are essential components in the abovementioned building technologies, they will also play an important role in the building sector (Marscheider-Weidemann et al., 2016). One example for a critical raw material in innovative building technologies is indium used for thin-film photovoltaics. This paper analyses the criticality risks of indium with respect to different market penetration scenarios of thin-film-photovoltaics in the future as a part of sustainability goals in the German housing sector.

Criticality assessment

Photovoltaics (PV) in combination with energy storage systems are assumed to play an important role for the expansion of renewable energy sources. Integrated in the housing sector, PV generates electrical energy not only for heating devices but also provides energy for lighting, household electricity and even other sectors like electric mobility (Öko-Institut e.V., 2015).

Thin-film photovoltaics open up possibilities for technical and aesthetic integration as they can be integrated on the building envelope (Hegger et al., 2016). Currently market-relevant technologies are amorphous silicon (a-Si), micromorphous silicon (µ-Si), copper-indium-disulphide (CIS), copper indium gallium diselenide (CIGS) and cadmium-telluride (CdTe). The critical raw material analysed for thin-film PV is indium, contained in CIS and CIGS technology, which is indicated as CI(G)S. CdTe also contains indium, but is not regarded further as this technology is assumed to be phased out of the German market due to the lower efficiency developments compared to other thin-film technologies and the contained potentially toxic cadmium. In addition, the a-Si technology contains small amounts of indium in the indium-based ITO TCO substrate. Since it is assumed that this substrate will be substituted within the next decade, this technology is also not further considered. (Wuppertal Institut, 2014)

The criticality of indium is reasoned by its vulnerability risks, which is given by high importance for future technologies with expected market growth, like indium tin oxide (ITO), a key material for manufacturing liquid crystal display (LCD) panels. In addition, indium is not substitutable for the required functionality. Indium also experiences high supply risks, which are another important factor in its criticality. Crucial indicators for those are the by-product dependency on zinc production, the country production concentration, country risks and the missing secondary supply by recycling. (Erdmann, 2011; EU, 2014; Marscheider-Weidemann et al., 2016)

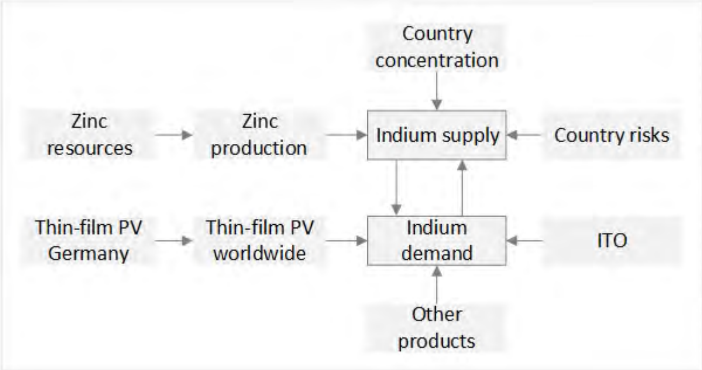

Figure 1. Criticality of indium – considered aspects

The availability of indium is significantly affected by the ratio of supply and demand. All the risks which classify indium as critical have impacts on demand or supply of indium. Even country risks, which include different political and social aspects, can limit the available indium supply. To take that into account the assessment of criticality is based on sector specific material flows. The identification of risk impacts on future scenarios requires a dynamic approach to analyse the developments until 2050.

This is done by a system dynamics (SD) simulation model. The SD approach was created at the Massachusetts Institute of Technology in the 1950s by Forrester and allows the simulation of non-linear behaviour of socio-economic systems over time (Bossel, 2004). For this analysis it is used to model material flows by stocks and flows in order to simulate potential future developments. Future developments of thin-film PV are therefore based on a Wuppertal Institute study, which worked out different scenarios of photovoltaics installation for Germany up to 2050 based on another seven studies on energy scenarios for Germany (Wuppertal Institut, 2014). The indium model is simulated up to 2050 based on these scenarios. As this is a long time-frame with high uncertainties the simulation results are additionally marked with the year 2035.

Simulation model

Main objective of the simulation model is to quantify the supply and demand ratio of indium within the next decades assuming different possible future scenarios in order to assess criticality risks of indium and derive recommendations.

System boundary

The modelled system is based on the global indium supply and demand. As a by-product of zinc, the indium-supply is linked with zinc mine production and is thus limited by zinc resources, defined as currently known mineral deposits (Graedel et al., 2014). Furthermore, indium supply is affected by country concentration and country risks. Indium demand is composed by global demand of thin-film PV, ITO and others. In turn, thin-film PV developments in Germany are linked to the global market.

Model

The supply of indium is based on zinc production, as more than 95% of primary indium is produced as by-product of the zinc refining process (Schwarz-Schampera, 2014). Currently 1.9 * 109 metric tonnes (t) of zinc are known to exist within the earth’s crust (USGS, 2017). The current economically mineable zinc reserves amount to 220.000.000 t (USGS, 2017). The annual production of zinc refinery is defined by zinc refining rate, which is related to previous developments depending on global economy growth. For the indium model, the growth rate of zinc refining is determined by the conservative estimation of 2% up to 2020 (Dorner, 2015). The indium supply is calculated by the indium concentration in refined zinc ores, which ranges between 0.002 and 0.02 percent (Schwarz-Schampera, 2014). The average indium concentration depends on the supply-demand ratio. If demand increases, more of low concentrated ores will be needed and vice versa.

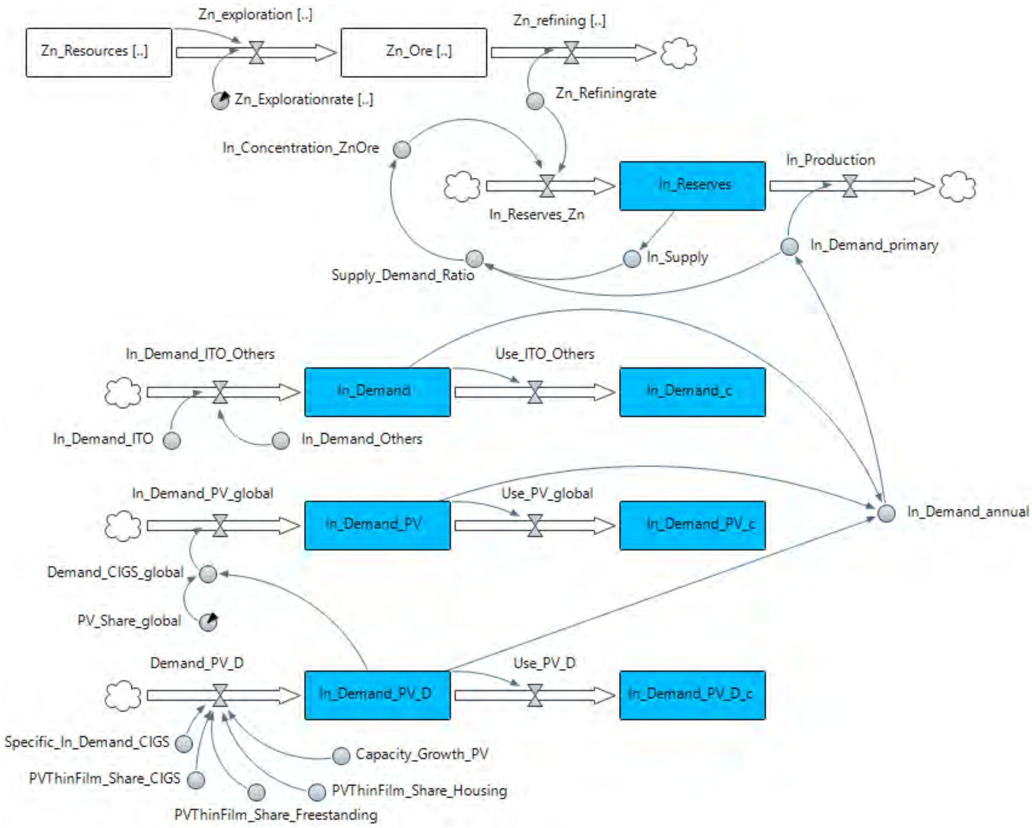

Figure 2. Indium model

An important risk factor for indium supply is the country concentration. If individual countries have a very high share of the world production of a specific raw material, they can influence the quantity of traded raw materials as well as dictate market conditions due to their market power. The country concentration is mostly measured by the Herfindahl-Hirschman Index (HHI) and is calculated as the sum of the squares of market share (Buchholz et al., 2014). In case of indium, which is a by-product of zinc production, high country concentrations affect zinc refining as well as the indium primary production. The share is broken down as follows: zinc refining production: China 34.1%, Rep. of Korea 6.7%, India 5.4%, others 53.8%. Indium production: China 55.2%, Rep. of Korea 18.0%, Japan 8.6% and others 18.2% (Brandenburg et al., 2016).

Another risk factor of indium supply is the country risk. The assessment is based on the World Governance Indicators (WGI) of the World Bank, shown in Table 1 (EU, 2014). This indicator also includes social aspects of resource supply, as it includes measurements like voice and accountability or corruption.

Table 1. World Governance Indicators (World Bank, 2016)

Indicator	Description
Voice and Accountability	Measures the possibility of country's citizens to participate in selecting their government and includes freedom of expression, freedom of association and free media.
Political Stability and Absence of Violence/Terrorism	Measures the probability of political instability and/or politically motivated violence and terrorism.
Government Effectiveness	Assessment of the quality of public services, civil services and their independence from political pressure, policy formulation and implementation and the credibility of governments commitment.
Regulatory Quality	The indicator assesses the ability of the government to implement laws and regulations that permit and promote private sector development.
Rule of Law	Assessment of confidence in and abide by the rules of society. It also includes quality of contract enforcement, property rights, police, courts and the probability of crime and violence.
Control of Corruption	Measures the extent to which public power is exercised for private profit, all forms of corruption and "capture" of the state by elites and private interests.

The governance indicator is measured on a scale from approximately -2.5 to +2.5. Higher values correspond to better governance, whereas the lower values correspond to higher risks. Regarding the WGI of the main zinc and indium producing countries, two countries have noticeable risks: China and India. In China all Indicators, except for government effectiveness, have negative values. The voice and accountability is particularly low, with a value of -1,58. India has similar values, but lower risks in voice and accountability (World Bank, 2016). To assess the risks depending on production countries within the indium model, the material flow of zinc and indium production is divided into the three main producing countries and others. Countries with high risks indicated by WGI were taken into account by subtracting their material flow in alternative supply scenarios. In case of indium a scenario without the supply from China is simulated.

The demand of indium is calculated by the sum of demands for thin-film PV, ITO and other products containing indium. ITO had a share of indium demand of 55 % in 2013 (Oakdene Hollins Research & Consulting, 2015) and is considered to be a growing market. Taking into account for the development of future demands and growth rate, the ITO indium demand would reach 274 t in 2035 (Marscheider-Weidemann et al., 2016). The annual demand for other products containing indium includes alloys, solders, LEDs, batteries, thermal interfaces as well as semiconductors and is assumed to be a constant 87.45 t per year.

The demand for thin-film PV is calculated in different scenarios based on the study by the Wuppertal Institute, which worked out different possible roadmaps for the development of thin-film photovoltaics in Germany, divided into rooftop installation, building integrated and freestanding. The scenarios are varied by the following scales: PV capacity increase, share of thin-film technology for each installation type (rooftop, building integrated, freestanding) and share of CI(G)S technology in thin-film PV. In addition the specific indium demand in CI(G)S is needed to calculate indium demand for CI(G)S technology in Germany. The specific indium demand includes developments of resource efficiency in the production of CI(G)S technology (Wuppertal Institut, 2014). Thin-film technology is a niche market, which has still growing potential worldwide. For the demand calculation it is assumed that the global demand growth of CI(G)S technology is proportional to Germany, with the current German share of worldwide installed PV of 16 % (Fraunhofer ISE, 2016).

Scenarios for Simulation

The criticality of indium depends highly on the global supply and demand ratio. As the exact estimation of future developments is not feasible, there are different possible scenarios simulated to cover the range between conservative to very high indium needs. Regarding the considered PV market for Germany, the demand side is simulated with three different demand scenarios of indium based on the Wuppertal Institute study. The minimum demand is given by a low growth of PV market and a continuous low share of thin-film PV (installed PV capacity 2050: ca. 50 GW). The maximum growth rate of PV market is combined with a growing share of thin-film PV (installed PV capacity 2050: ca. 260 GW). On the supply side two variants are simulated: the indium supply as a result of a conservative growth of zinc refinery and a variation of that without the supply of China.

Table 2. Energy scenarios for Germany based on (Wuppertal Institut, 2014)

PV capacity growth	Low	Intermediate	High
Installed capacity 2050	50 GW	120 GW	260 GW
Low share of CI(G)S	1,33%	1,33%	1,33%
High share of CI(G)S	34,88%	34,88%	34,88%

Results

The simulation results in Figures 3.1 and 3.4 show that under conservative estimations of indium supply, as a by-product of zinc refinery, the resources can meet the needs of indium even if the maximum demand scenario would occur. It can be assumed that the development of thin-film PV is not restricted by shortages of zinc or indium supply. However, the simulation shows that the demand supply ratio in the case of maximum demand can become low, especially when other sectors would grow more than currently expected. That can lead to economic risks regarding the price development and market power of the producing countries and mining companies.

The analysis of the supply risk indicators of indium has shown that the recycling potential of indium from end-of-life products is currently not developed to be economically feasible. The share of CI(G)S of the indium demand starts at 6 % and reaches a maximum of around 42% within the analysed scenarios (Figures 3.2 and 3.5), the German demand reaches a maximum of 8%. Forcing end-of-life recycling by collecting and developing recycling technologies only for CI(G)S PV modules will thus not recover considerable amounts of indium demand. Nevertheless, appropriate product design towards circular economy within the housing sector can be a possibility to minimize the large dependences on primary indium supply.

Besides the reach of indium to satisfy growing needs, the fact that 82 % of indium production comes from three countries, has different dimensions of risks. In particular, China produces more than half of the world's indium and is a country with high country risks, according to the World Governance Index. The exemplary simulation without indium supply from China (Figure 3.3 and 3.6) shows the big dependencies in case of rising indium demand. Economic risks by market power and shortages if China would limit delivery due to political instability or weaknesses in government can for example increase price volatility. Other than the primary raw material supply, this can affect further steps in the supply chain through to end products.

Another important issue which has to be mentioned is the effect on the environment, including social issues such as freedom of association and probability of violence. The aforementioned social risks indicated by the WGI raises the question whether supporting a system where the conditions for human work is not clearly defined agrees with sustainability goals aimed by using thin-film PV. In addition these country risks make it more difficult to regulate and control environmental impacts concerning ecological problems. Although the toxicity of indium is low and harmful effects are not reported, the available data about environmental exposure is not sufficient to make reliable assessments. (Schwarz-Schampera, 2014)

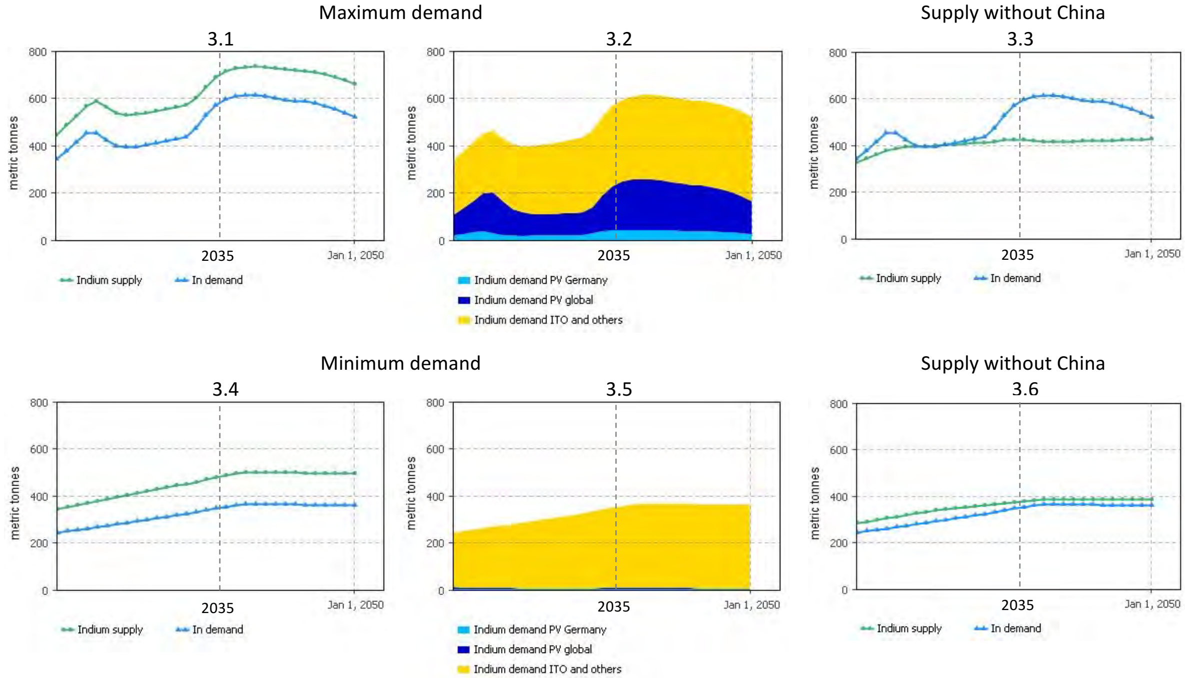

Figure 3. Simulation Results

Conclusion and Outlook

Regarding the indium supply under different thin-film-PV growth scenarios it is shown that current zinc refinery growth is enough to meet potential demands. Only the highest growth scenario can lead to a supply demand ratio which may influence competitive situation regarding the ITO market and commodity prices. Nevertheless, 82 % of indium production comes from three countries and more than the half of indium production is done by China. Reaching sustainability goals by developing resource efficient buildings can currently not be realized without accepting political, environmental and social risks due to the production of indium. Social risks are not easily quantified and difficult to verify as reliable information on mining conditions is rarely available. It has to be asked if and how the discussion about environmental impacts of raw materials mining should be included in aiming sustainability goals for the housing sector.

Should the CI(G)S technology for thin-film PV become a leading technology to reach sustainability goals it is recommended to develop economic recycling technologies to build up a relevant market for secondary supply. End-of-life recycling as a secondary material source can reduce risks induced by country concentration, as production of secondary material will be more widespread than primary production. In addition, conditions of secondary material production can be defined and controlled to meet sustainability goals also in social and ecological aspects. Therefore it has to be discussed how the housing sector can impact developments towards end-of-life recycling or even solutions for circular economies regarding innovative building technologies.

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Design to Thrive

Evaluating the hospital building sustainability: Applying a screening LCA and LCC to the new general hospital in Mechelen

Milena Stevanovic[1,2], Karen Allacker[1], Stéphane Vermeulen[2]

[1] KU Leuven, Faculty of Engineering Science, Department of Architecture, Leuven, Belgium, milena.stevanovic@kuleuven.be;
[2] VK STUDIO Architects, Planners & Designers, Roeselare, Belgium

Abstract: The past decade has been marked by an increased interest in the way hospital buildings are designed and operated. With the urge to decrease the negative impacts of the building stock around the world, healthcare facilities are equally called upon to respond to this matter. In order to assess the sustainability of hospital buildings, a quantitative approach using a life cycle thinking perspective, seems to be an appropriate method. However, due to the complexity and various medical preconditions a hospital needs to fulfil, no such method that would facilitate its sustainability assessment has yet been proposed. An attempt has been made to gain better insight in the environmental impacts and financial cost of a hospital building in Flanders. For this purpose, a screening Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) study has been carried out on the new general hospital Sint-Maarten in Mechelen. This paper focuses on the results of the aforementioned analysis. The aim is to pinpoint the major obstacles for such a quantitative analysis as well as to identify the hotspots from both an environmental and economic point of view. Furthermore, the results will serve as one of the important inputs in laying the cornerstones for the development of the quantitative sustainability assessment method for hospital buildings in Flanders.

Keywords: hospital, life cycle assessment, life cycle costing, sustainability

Introduction

Hospital buildings in Belgium, similar as for hospitals all over the world, are facing the challenge of lowering their environmental impact, while remaining focused on offering affordable and quality medical care to everyone (Stevanovic et al., 2017). As medical preconditions, such as hygiene and patient safety, prevail over any other in hospitals, it is not surprising that these settings have been slower than other corporations in implementing sustainable technologies.

Some efforts to facilitate the sustainability evaluation of hospital facilities have been made in the course of the past decade. This is reflected in the proliferation of the certification tools developed specially to address healthcare buildings. Among the best known ones are BREEAM, LEED, Green Star and DGNB. Most of these tools use a qualitative approach, i.e. they consist of a list of measures which are assumed to be sustainable and work on the principle "the more measures taken, the more sustainable the building". Regardless of their popularity among different building practitioners, resulting from their ease of use, the subjectivity in their assessment approach causes doubts whether the use of these schemes leads to truly sustainable buildings (Aspinal et al., 2012). An approach based on the life cycle thinking perspective, seems to be more appropriate when analysing the sustainability of hospital buildings (Stevanovic et al., 2017). However, a method relying on such an approach in the context of hospitals is still lacking to date. Please note your original selection of forum may have changed to another considered more appropriated for your paper. This information is available when you upload your final paper.

Scope

The main goal of this paper is to gain better insights into the environmental impacts and costs of hospital buildings in the Flemish region. For this purpose, a screening Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) study has been carried out on the general hospital Sint-Maarten in Mechelen (expected to be finished by 2018). The aim of applying the aforementioned study, is to unravel the major obstacles for a quantitative approach when assessing the hospital building sustainability, as well as to identify the hotspots from both an environmental and economic point of view.

The subsequent paragraphs describe the methodology used and discuss several important methodological issues worth the attention when proposing a more holistic quantitative sustainability assessment method for hospitals.

Methodology

Life cycle assessment (LCA)

Life Cycle Assessment (LCA) is a standardized methodology for tracking and reporting the environmental impact of a process or product (i.e. good or service), including a building, over its entire life cycle (ISO 14040, 2006). Though it is still advancing, especially in the aspects dealing with ultimate impacts on human health and ecosystem quality, the technique has become an internationally recognized approach to assess the environmental impact of products or processes (Trusty et al., 2007). For the assessment of the hospital in Mechelen the MMG ("Milieugerelateerde Materiaalprestatie van Gebouwelementen") method is used. The MMG method is a Belgian LCA method developed for assessing building components and buildings (Allacker et al., 2013; Trigaux et al., 2013). A detailed description of the MMG method can be found in Trigaux et al (2014). The MMG method was converted into an Excel-based tool at the Architectural Engineering research division of KU Leuven and this tool was used for the screening LCA of the hospital building. The considered environmental impacts covered in the MMG method consist of the impact categories as defined by the CEN TC350 standards (CEN, 2011). These are referred to as CEN indicators in the method and are listed as follows: global warming potential, depletion of the stratospheric ozone layer, acidification of land and water sources, eutrophication freshwater and marine, photochemical oxidant formation and abiotic depletion of non-fossil resources. Additionally, based on the International Reference Life Cycle Data System (ILCD) Handbook (2010) and in consultation with the Flemish-Belgian policy makers, a list of other impact categories were added, further referred to as CEN+ indicators. The list of additional indicators include human toxicity (cancer and non-cancer effects), particulate matter formation, ionising radiation (human health), ecotoxicity (terrestrial, freshwater and marine), land use: land occupation (agricultural/forest and urban) and land use: land transformation (tropical rain forest).

Life cycle costing (LCC)

Besides the environmental impact, costs are an important issue in the sustainability context to guarantee affordability. Affordability does not only relate to the investment costs, but also to costs for operating the building and costs for replacements and refurbishments. The financial implications of the general hospital Sint-Maarten in Mechelen are assessed through the life cycle costing (LCC) approach, a well-known approach to estimate the costs related to different life stages of a building. Within the LCA tool developed by the division of Architectural Engineering, also a module is included to calculate the life cycle costs of the building. The tool hence allows for simultaneous estimations of both environmental impacts and financial costs (Wijnants et al., 2016). To allow for decisions based on environmental impacts and financial costs simultaneously, it was necessary to have an equal unit for both. For this reason, the environmental impacts are translated into monetary values by calculating the external environmental cost. For the assessment of the hospital building, the tool of the Division Architectural Engineering was used for the calculation of the life cycle environmental impacts (LCA) and financial costs (LCC).

The building life cycle considered within the LCA and LCC method, was divided into four phases according to the European CEN standards (CEN 2011). The phases include production, construction, use and end-of-life (EOL) (Figure 1).

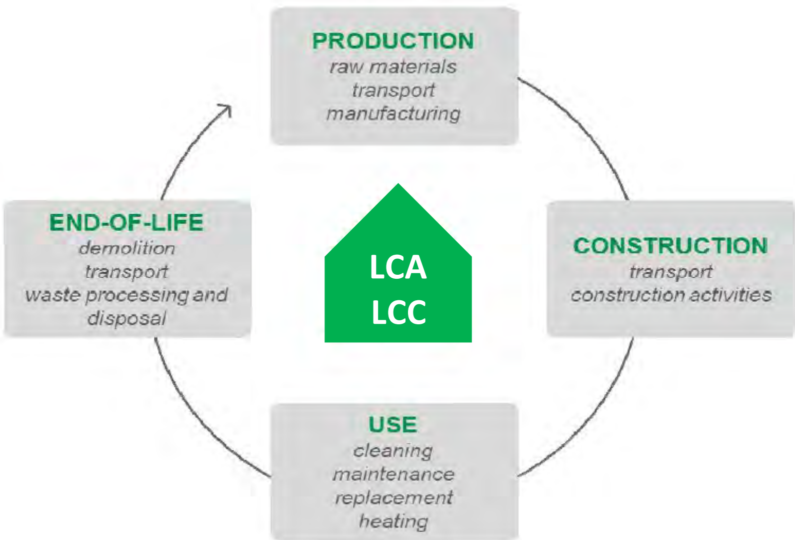

Figure 1. Life cycle phases (adapted from Trigaux et al., 2014)

Case study

Over the past twenty years, a sharp reduction of patient beds and acute care in Flanders has caused hospitals within the same network to merge into one new building, often relocated outside the city centre. This movement was largely encouraged by the Flemish government and VIPA ("Vlaams Infrastructuurfonds voor Persoonsgebonden Aangelegenheden") based on the strategic plan for changing the healthcare landscape. This plan provided infrastructure grants to hospitals moving to a new campus outside city centres (Van den Holen et al., 2008).

In 2007, a competition for the general hospital in Mechelen, fusing three campuses of the Sint-Maarten network into one new construction, was launched. This new, 723-bed hospital was chosen as case study for the screening LCA and LCC study. The project is a result of the collaboration between VK Architects & Engineers, a company with expertise in design and engineering related to the healthcare buildings and Ingenium, a consultancy office specialized in sustainable solutions in the built environment. The first company provided the solutions for the architecture, hospital programming, landscape design and fire safety, façade and acoustical engineering; whereas the second was responsible for the implementation of all technical equipment typical for the hospital.

The building is located nearby the ring road of Mechelen (Belgium) (Figure 2). To achieve a more compact setting, and thus reduce the envelope, construction cost and energy loss, the designers have opted for a monoblock hospital (hospital building typology is described in Prasad (2008) and Wagenaar (2006)).

Figure 2. Location of the hospital (left, © Google maps) and the construction site progress in November 2015 (right, © VK Architects & Engineers)

Data collection and assessment scope

The scope of the screening LCA and LCC study was defined as limited to the building without it surroundings. All life cycles of the hospital building are included in the scope. Moreover, all building parts are included except for the technical installations for heating, cooling, ventilation and medical apparatus. The latter were excluded in the screening study because of lack of data and because these are less influenced by the building design. A lifespan of 30 years is assumed.

For the life cycle inventory phase, a two-step procedure is used. Firstly, data regarding the materials used, energy demand, water consumption, and quantities of building elements were searched for. These were all provided by the company VK Architects & Engineers. The information received consisted of building plans, detailed specifications of materials used and Excel files with quantities of building elements. Based on this information, 93 building elements were defined as the main construction components of the hospital. Based on the BB/SfB classification system implemented in the LCA and LCC method (Trigaux et al., 2014), the building elements were classified into ten categories: (1) floor on ground, (2) external wall, (3) loadbearing internal wall, (4) non-loadbearing internal wall, (5) storey floor, (6) stairs, (7) column (free-standing), (8) flat roof, (9) windows and (10) doors. Secondly, the inventory for each of the materials and processes identified had to be collected. For this step the Ecoinvent database version 2.2 was used and adapted for the context of Belgium (Trigaux et al., 2013). Many of the products/processes were already included in the calculation tool (developed prior to this research). Several were however lacking as the tool was originally developed for residential buildings. The lacking materials, specific for hospital buildings, were modelled and exported from the SimaPro software.

Results

The results of the environmental and financial costs are presented at the building level. The electricity demand is estimated at 136 kWh/m².year based on the VIPA's standards. This includes electricity for ventilation, lighting and medical apparatus. The hospital is heated with natural gas with a gross heating demand of 118 kWh/m².year (net value received from the VK Engineering, system efficiency of 85 % is assumed).

Figure 3 shows the environmental impact of the various life cycle phases, expressed in euro (external environmental cost) per m² floor area. The most impactful phases concerning the CEN indicators include the production, heating and electricity use, covering 10%, 32% and 53% of the life cycle environmental cost respectively. Regarding the CEN+ indicators, the most responsible phases include production (25%) and electricity use (62%), followed by heating (3%), water consumption (2%), cleaning processes (2%) and demolition (2,5%). The remaining 3,5% is distributed between transport to site, construction, small and big maintenance, replacement, refurbishment of the work sections and building elements and transport to EOL and disposal phases.

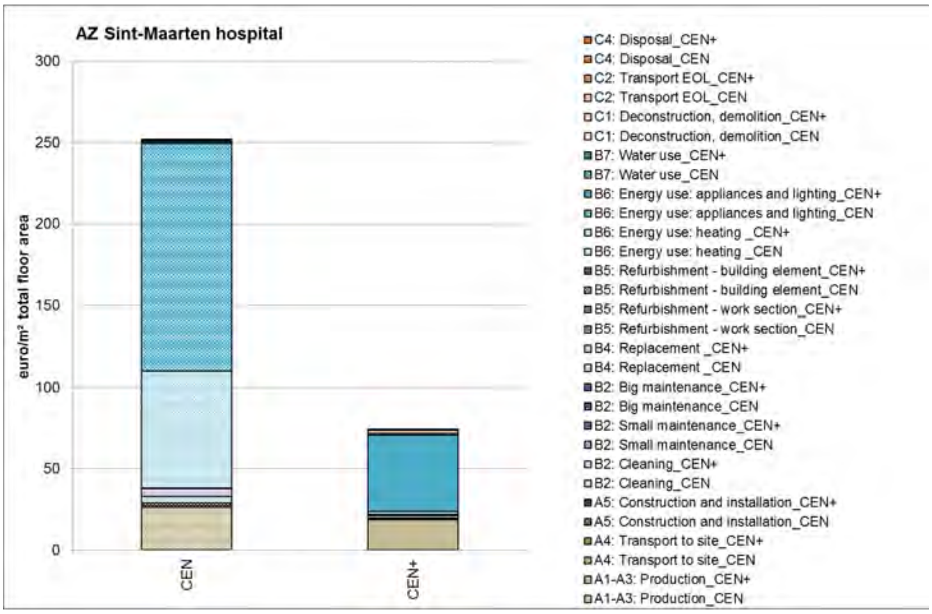

Figure 3. Environmental impact of the Sint-Maarten hospital subdivided per life cycle stage

Figure 4 shows the contribution of the various impact categories to the overall environmental impact. In the group of CEN indicators, it can be clearly seen that the most significant impacts are global warming and eutrophication, covering 92% and 7% of the total environmental cost. Within the CEN+ indicators, the impacts contribute mostly to human toxicity, both cancer and non-cancer effects (46% and 15%), particulate matter (33%) and land use (4%).

From a financial point of view, the most important life cycle stages are the construction of the building and operational electricity use, followed by spatial heating, cleaning and water use (Figure 5). The total financial cost of the hospital's life cycle amounts to 2447,61 euro/m² total floor area, while the investment cost equals 946 euro/m² total floor area (i.e. without technical services). The costs are based on data from a Belgian generic cost database (ASPEN, 2015). The investment cost estimated by VK Architects & Engineers was 10% higher compared to the cost estimation with the KULeuven-MMG model. Based on this validation, the latter is found sufficiently accurate.

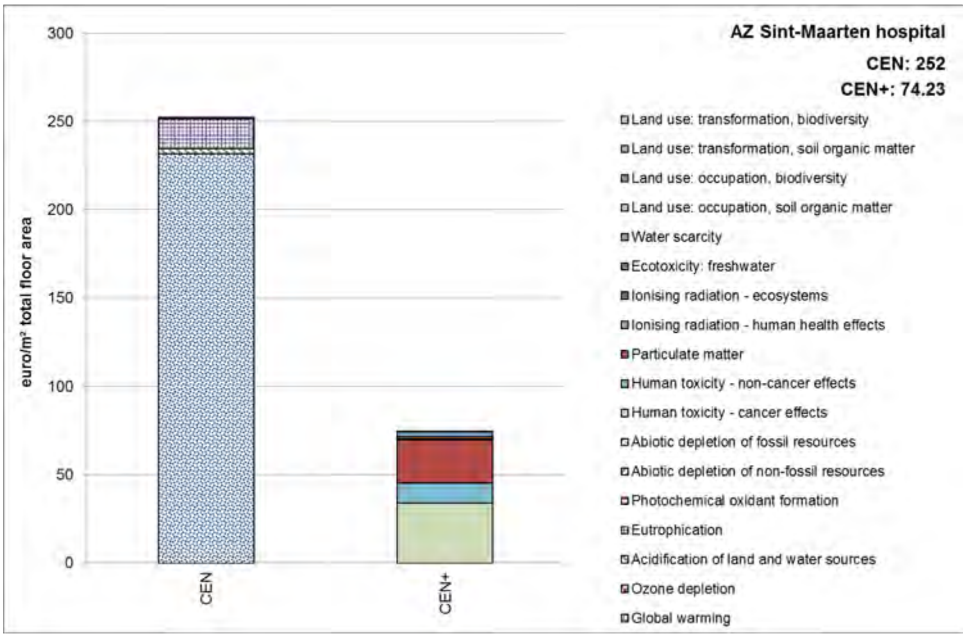

Figure 4. Environmental impact contribution to both CEN (left) and CEN+ indicators (right)

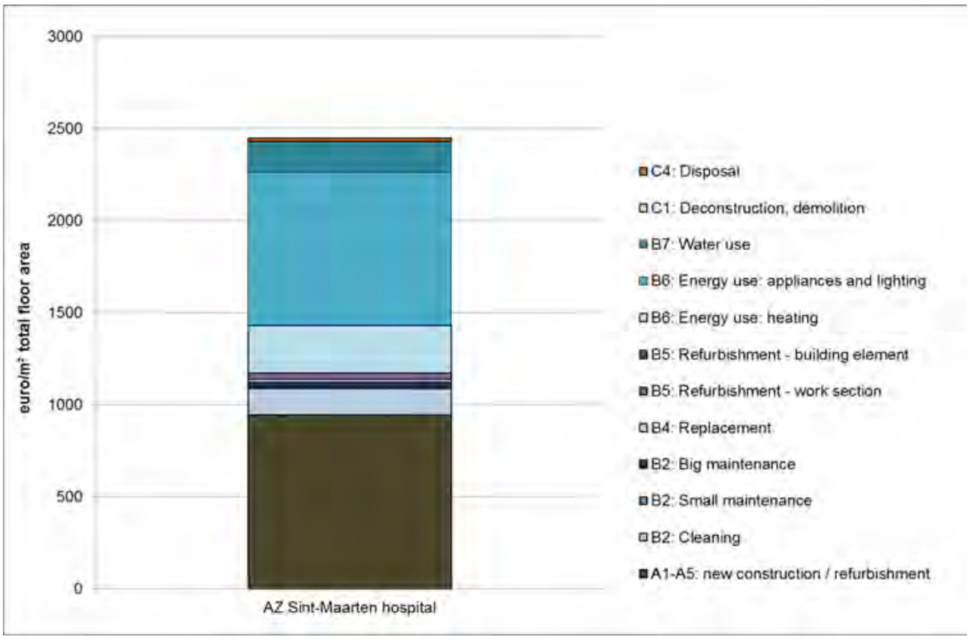

Figure 5. Financial cost of the Sint-Maarten hospital, sub-divided per life cycle phase

Conclusions and further research

This analysis is seen as one of the valuable steps towards the development of a more holistic sustainability assessment of healthcare settings. The screening LCA and LCC of the Sint-Maarten hospital led to several important learnings.

First of all, it was clear that the existing methodology of the research division 'Architectural Engineering', combining the LCA and LCC approach, needed several adaptations to ensure its applicability to hospital buildings. For example, freestanding columns (a common element in hospital buildings) were lacking in the original tool and had to be added. In the context of the Sint-Maarten hospital, the columns are modelled in reinforced concrete, however in future different materialization should be taken into account. Hospital doors (hermetically sealed) differ from the ones used in residential buildings due to cleaning regimes and prevention of cross-contamination through bacteria build up, these had to be added to the MMG database. Many other building components and materials had to be added which are not used in residential buildings, such as for example several floor coverings including a cavity floor structure of steel, sandwich panels for the cold storage and freezer units, a polished concrete floor (technical rooms) and a suspended ceiling made of steel slats used to cover technical pipes. Furthermore, the analysis revealed that often hospitals are more complex than residential buildings, requiring the combination of many more building components. This higher level of complexity required some adaptations to the original model. Finally, for the LCA analysis, many of the inventory data were extracted from the BIM model provided by VK Architects & Engineers. This step revealed that the structuring of the BIM model was not always in line with the MMG – LCA structuring and required quite a lot of time to calculate the correct bill of materials. In order to make this step more smooth, the BIM model will need to be better aligned with the LCA structure in future.

Secondly, the analytical results allowed to identify three major hotspots: a) electricity use for hospital appliances (HVAC and medical apparatus) and lighting, b) spatial heating and c) material production processes.

In the next phase, based on the outcomes of this study, the first cornerstones for the development of the quantitative sustainability assessment method for hospitals will be laid down. One crucial step to be made is to elaborate an extensive database with predefined technical solutions for each of the building elements to be used in the early design phase. This would allow the designers to make a screening LCA without the need for extensive data input. A second step in the further elaboration of the method, is to the heating, ventilation and air-conditioning (HVAC) installations typical for hospitals and integrate these into the LCA and LCC method. A third issue that will be focused on is the integration of transport from and to the hospital in the sustainability assessment method.

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Parametric Investigation of Three Types of Brick Bonds for Thermal Performance in a Hot Arid Climate Zone

Khaled Tarabieh[1], Sherif Abdelmohsen[1,2], Yomna Elghazi[3], Rana El-Dabaa[3], Asmaa Hassan[4] and Mariam Amer[1]

[1] Building Sciences Lab, Department of Architecture, School of Sciences and Engineering, American University in Cairo, New Cairo, Egypt, ktarabieh@aucegypt.edu
[2] Department of Architecture, Faculty of Engineering, Ain Shams University, Cairo, Egypt, sherifmorad@eng.asu.edu.eg
[3] Department of Architectural Engineering and Environmental Design, College of Engineering and Technology, Arab Academy for Science, Technology and Maritime Transport, Cairo, Egypt, rana.bahaa@aast.edu
[4] Department of Architectural Engineering, Faculty of Engineering and Technology, Future University in Egypt, Cairo, Egypt, asmaa.gamal@fue.edu.eg

Abstract: Bricks are significant building elements that are heavily utilized, whether for structural or ornamental purposes. Nevertheless, little has been published on the relationship between brick bonding, shape, and extrusion, and the impact on energy performance. This paper investigates the impact of different brick bond types and projections on building energy using a custom algorithm. This investigation was conducted in two phases on 24 cases for a south façade. The first phase investigated three different brick bonds for their thermal performance: Running, English and Flemish bonds. The second phase involves parametric simulations to evaluate energy consumptions for three extrusion values [baseline "no extrusion", ¼ brick extrusion, and ½ brick extrusion] and four different extrusion percentages (ranging from 15% to 60%). The first phase results show no significant differences in energy performance for the base case. The second phase results show that the performance achieved was 26% less than the base case. This was accomplished using the Flemish bond with either 30% wall area extruded with half brick length, or 60% bricks extruded with quarter brick length. The preliminary findings indicate a relationship between extrusion and energy performance. Further studies should include in-situ testing and investigation of patterns under different climatic zones.

Keywords: Brick patterns, façade design, energy simulation, parametric tools

Introduction

Bricks were historically utilized as an exterior envelope material in buildings as well as a paving material in landscape applications. In exterior walls, bricks are often left to define the colour of the façade in addition to its structural role in the skin. Bricks may be painted or covered with plaster or cladding of different materials depending on the type of bricks or façade design intent. The source of brick manufacturing can vary by mix and additives with the intent to improve strength, aesthetic colour and look. Using bricks as an ornamental feature of the exterior wall appears in a number of architectural styles. Little is mentioned in the literature on the role of brick bond types, projections and ornaments and few discuss the role of brick formations and bonds in the thermal performance of the wall. The goal of this paper is to provide an exploratory investigation of the impact of different brick bond types and variation in the associated brick projections on building energy use. The research objective is to utilize parametric and thermal analysis tools to develop wall configurations that are sensitive in their look and form to solar radiation; and thus a performance driven design for the determination of wall design thickness and thermal mass to impact the overall building energy use intensity.

Literature Review

To approach the research goal, we conducted a literature review in three primary related areas: (1) Traditional Brick Properties & Patterns, (2) Performance and Energy Analysis of Brickwork, and (3) Potentials and Limitations of Parametric Techniques in Brick Wall Design. A number of studies discuss traditional brick properties and patterns. Among the recent studies, Asdrubali et al. (2014) clarified the importance of material thermal flux to evaluate the in situ thermal transmittance of a material to determine actual wall performance. Lucchi (2017) explored the different thermal properties of brick masonry though a comparative analysis and in situ experiment on industrial bricks used today in Italy versus historic brick masonry. The regular measures taken simulators to examine the thermo-physical behaviour of traditional masonries were presented. The base of the evaluation was built on conventional research of brick masonry geometrical survey, VI, IRT, and hot-disk techniques.

Several studies evaluated the thermal performance and energy analysis of brick work in exterior walls, but generally with traditional and static brick configurations. Rhee-Duverne and Baker (2013) examined the experimentation procedures and modelling software used in testing the thermal performance of various types of traditional solid brick walls. Few studies took into consideration the different brick bonding arrangements to achieve indoor thermal comfort. The Brick Industry Association (B.I.A., 2016) demonstrated some of the significant parameters influencing building envelope performance, including mass, wall thickness, and thermal resistance, and highlights the importance of modelling and simulation to conduct thermal analysis especially for complex buildings.

Several approaches have been adopted to demonstrate the potential and limitations of parametric techniques, mainly in the use of generative and parametric modelling in the design, configuration, and construction of brickwork. Cavieres et al. (2011) used generative rules and functions to inform the construction of load bearing concrete masonry during conceptual and design development phases. The work of Al-Haddad et al. (2012) investigates the link between the structural representation of complex brickwork and its physical construction using parametric modelling. Gentry (2013) explored the prospects of reaching a middle ground between brickwork design flexibility and allowing for design reasoning and material logic exploration.

As for performance based approaches, most of the research is directed to exploring the relation between brickwork configurations and daylighting analysis. Several techniques have been adopted in that regard, especially using genetic algorithms. Little has been done to explore the potential of optimizing thermal transmittance in unconventional brickwork configurations. Genetic algorithms have been widely discussed and adopted in this context for form generation, daylight analysis and structural performance evaluation. According to Omidfar (2015), these approaches allow designers to examine the details of different façade variables using shading systems with decorative patterns. Based on the previous review, a gap in current research is evident in the exploitation of parametric and generative modelling techniques in the reduction and optimization of thermal transmittance in typical brick wall configurations.

Approach

The overall research approach follows the framework shown in Figure 1 in three parts; a) Descriptive, b) Analytical using simulation software and in situ measurements, and c) Comparative approach between simulation results and in situ measurements. The descriptive part addresses building typology and characterization. The analytical part uses parametric simulations and in situ measurements to identify optimum wall characteristics, and the comparative part aims to compare between the simulation results and in situ measurements to recommend and validate best cases and explore the impacts of promoting or optimizing a specific bonding and projection type. The overall approach is shown in Figure 1, however, the main scope of this paper is the investigation of the thermal performance simulation part, as highlighted below.

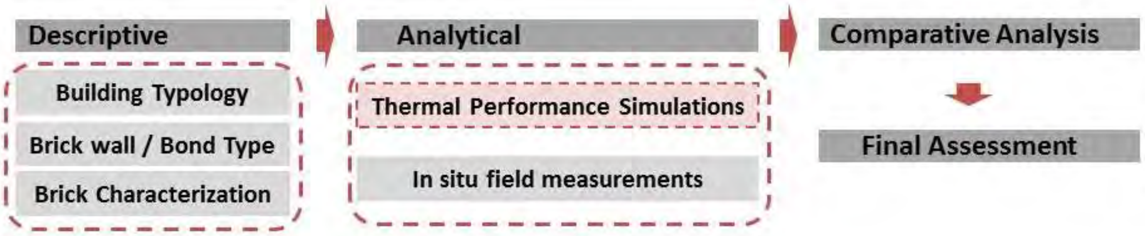

Figure 1. Research Approach

Evaluation method

The evaluation method takes the form of an input-output I/O model as in Figure 2, comprised of four steps; 1) determination of inputs, 2) thermal performance simulation, 3) performance evaluation using analytical tools, and finally 4) tabulation of the outputs.

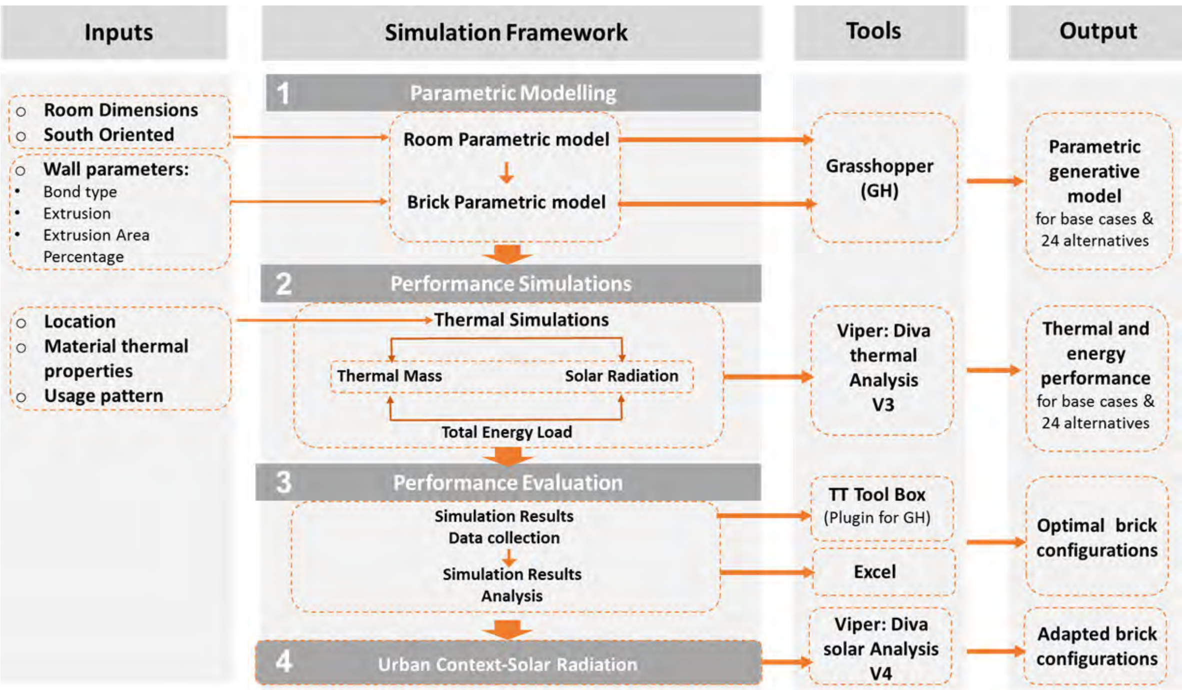

Figure 2. Research Methodology

Preliminary study

The research integrates energy consumption and solar radiation with solar parametric optimization algorithms using Grasshopper and DIVA-for-Grasshopper respectively to conduct multiple thermal simulations. Annual thermal simulations were conducted on a residential space with different brick configurations and extrusion values. A south oriented enclosure was modelled using Grasshopper to test the thermal performance of different brick bonds in a hot arid climate zone. The brick wall was positioned as the southern facade. A brick size of (20cm x 10cm x 6cm) is used in the construction of all wall types. The detailed parameters are shown in Figure 3 and Table 1.

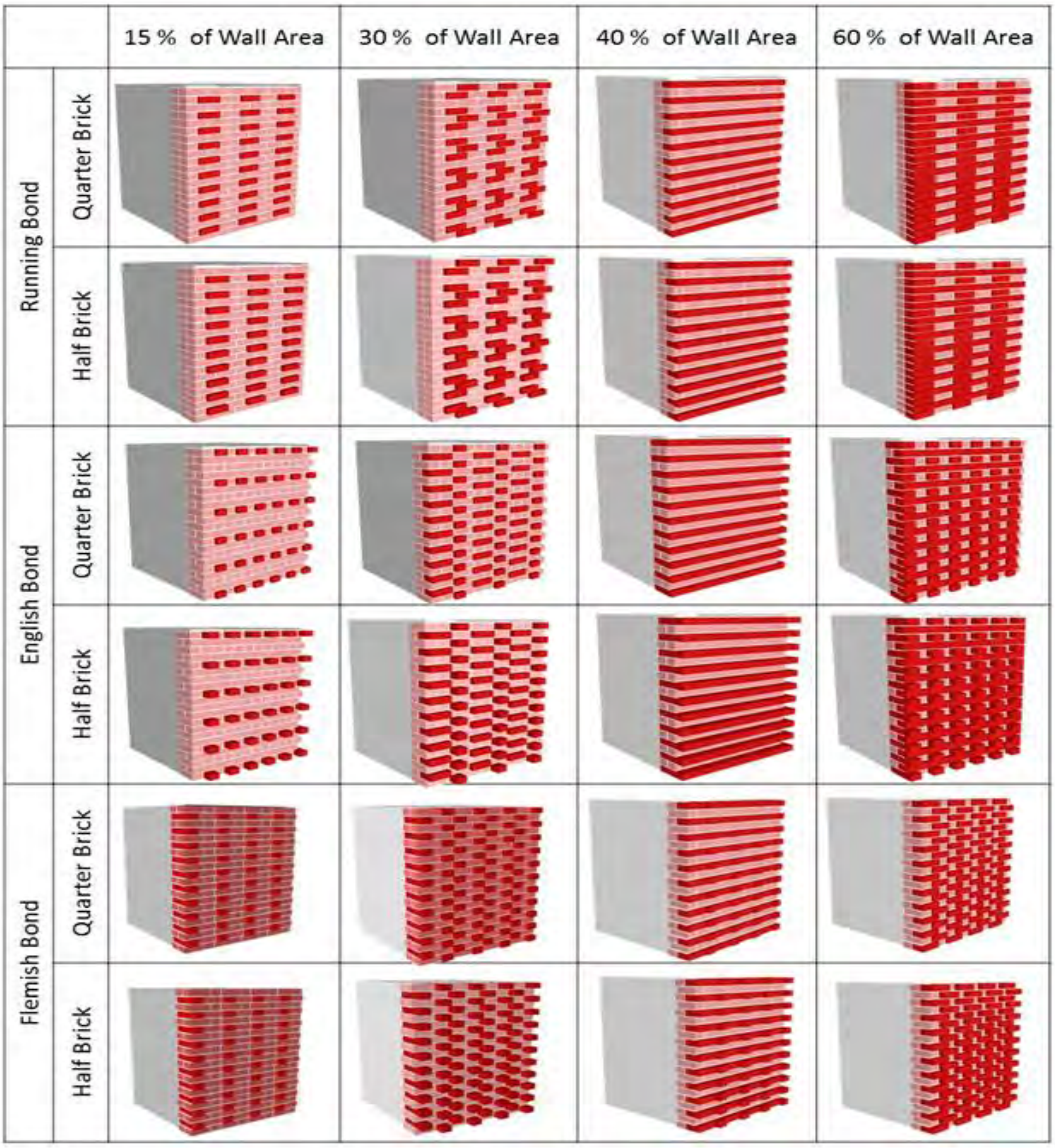

Figure 3: Different area percentages of extruded bricks and values of extrusion for the tested cases

A script in Grasshopper was developed to generate brick wall design variations based on three types of brick bonds; Running, Flemish and English bonds. The three types of bonds that represent the baseline case (zero brick extrusion) are shown in Table 2. The script initiates a basic brick unit with a number of runs and iterations. 24 cases of different brick wall types and different projections were simulated. The figure below shows a matrix relationship of bond type denoting the extent of projection (quarter or half brick size) and the percentage of wall extruded (15%, 30%, 40% or 60%). Later in the paper we will refer to a specific selection as bond type (x brick size, y %).

Table 1. Simulation Parameters

Space Parameters	
Climate Zone	Hot Arid
Floor level	Ground floor
Orientation	South
HVAC set points	
Heating set point	22° C
Cooling set point	26° C
Space thermal properties and material reflectance	
External wall U-Value	Custom 3-layered material: (brick, mortar & brick) with 35% reflectance
Internal walls /Ceiling /Floor	Adiabatic

Table 2. Extrusion values in the three types of bonds

	Running Bond	**Flemish Bond**	**English Bond**
Baseline case: Zero Extrusion			
Extrusion value: Quarter of a Brick			
Extrusion value: Half of a Brick			

Procedure

The brick configurations were based on two main sets of variables: (a) area percentage of extruded bricks, and (b) extrusion distance. Four cases were tested for the area percentage of extruded bricks: 15%, 30%, 45% and 60% respectively. The extrusion value was represented by two steps: ¼ brick and ½ brick extrusion, as shown in Table 3. The simulations were conducted in two phases. First, a set of base case simulations were conducted for three different brick wall bond types: Running Bonds, English Bonds and Flemish Bonds. Second, the annual energy consumptions were calculated for the three extrusion values (baseline, ¼ brick and ½ brick extrusion) and the different percentage of the extruded bricks on the facade (from 15% to 60%).

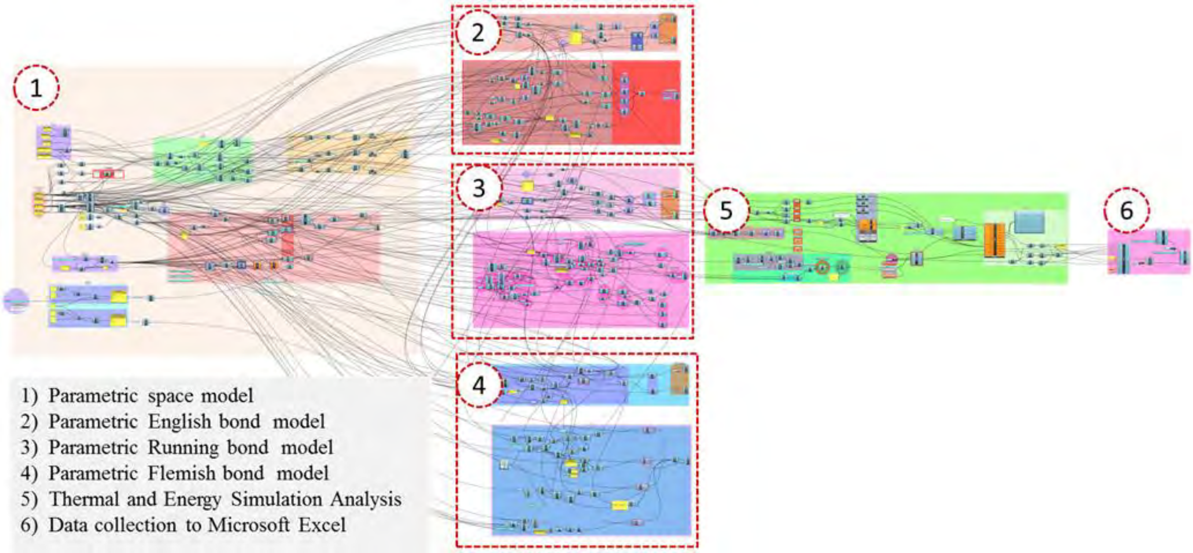

Figure 4: The comprehensive parametric definition in Grasshopper

A closed parametric loop was developed using Grasshopper and DIVA to evaluate the thermal performance of the three brick configurations (Running, English and Flemish bonds) with different brick extrusion values (baseline, ¼ brick and ½ brick extrusion) and different percentages of the extruded bricks' area from the facade (15% to 60%). A large number of simulations was conducted to reach the optimum bond case and optimum percentage of extruded bricks. Subsequently, an annual energy simulation was conducted for a south oriented residential space with different brick configurations.

Output results

The results were classified into three cases: ¼ brick extrusion, ½ brick extrusion, and base case (without any extrusion value) for each bond (Running, English and Flemish), as shown in Table 3. The best performing types resulted from the Flemish bond configuration, with 60% of the wall area made of (¼ brick extrusion) and with 30% of the wall area made of (½ brick extrusion) with a lowest energy consumption of 97 kWh/m^2, as highlighted in Table 3. The worst case however with the highest energy consumption rate at 133.14 KWh/m^2 was the English bond with 15% ¼ brick extrusion. Table 3 reveals that the ½ brick extrusion in the Flemish bond achieved the best energy consumption with extrusions ranging from 15% to 60%.

This is confirmed as the highest thermal mass wall of the ½ brick extrusion Flemish bond achieves the best energy consumption results. By looking closely at each bond type, it is obvious that the Flemish bond case achieved are the best performing, followed by the English and the Running bonds. The extrusion percentage seems to play a significant role in the results of the English and the Running bonds. For example, the ¼ brick English bond results all performed better than the Running bond, except for the 15% extrusion in the English bond.

Table 3. Results of normalized energy use intensity (EUI) for each case in Kwh/m^2

Bond Type	Percentage of wall Extrusion of brick	15%	30%	45%	60%
Running Bond	Base Case	133.53			
	Quarter Brick Extrusion	115.75	112.78	107.01	101.82
	Half Brick Extrusion	109.97	105.17	102.60	128.64
English Bond	Base Case	133.43			
	Quarter Brick Extrusion	133.14	108.33	104.04	100.90
	Half Brick Extrusion	129.27	102.15	103.29	100.17
Flemish Bond	Base Case	131.90			
	Quarter Brick Extrusion	107.46	100.29	99.19	97.46
	Half Brick Extrusion	103.45	97.90	99.02	100.55

As shown in Figure 5, the lowest energy consumption rate is achieved at the 15% extrusion of the wall area in all cases except for the ¼ brick extrusion in the Running bond. Also, the 60% extrusion seemed to give the best energy consumption rates in most cases, as it increases the thermal mass of the wall, except for the ½ brick extrusion in the Flemish bond and the ¼ brick extrusion in the Running bond.

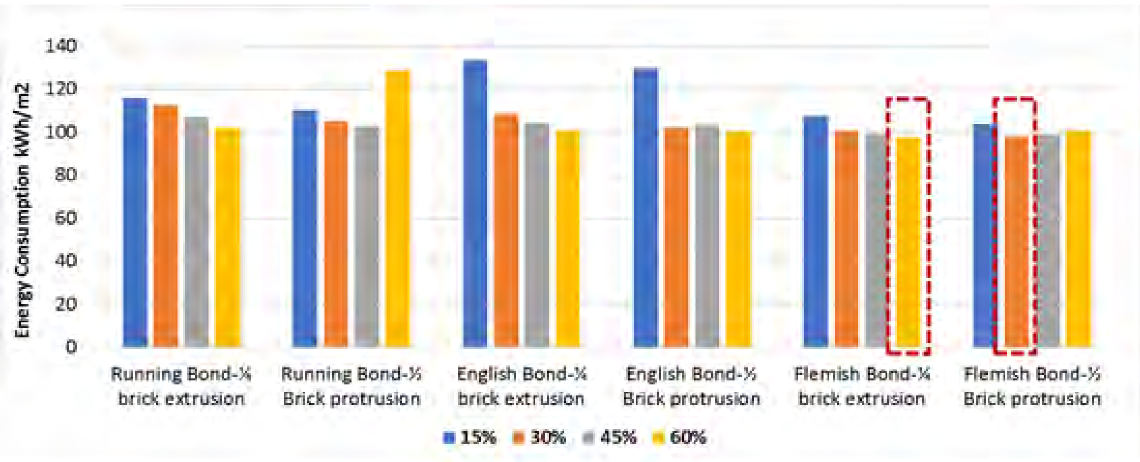

Figure 5. Graph comparing between the energy consumption in each case

Conclusion

It is evident that a relationship can be observed between the brick bond types, their brick projection and the percentage of both this projection and the volume of this projection for the tested cases. The increase in the thermal mass resulting from brick projection has an obvious impact on the thermal performance of the wall. It is also worth noting that the work presented is theoretical in nature, future development of this work may include in-situ field testing for the nominated wall types under the specific conditions relevant to the hot arid climate zone, and investigation of the different patterns that can be generated in relation to different orientations and climatic zones.

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Design to Thrive

From Sink to Stock: The Potential for Recycling Materials from the Existing Built Environment

Irmak Turan[1], John E. Fernández[1], Christoph Reinhart[1], Paulo Ferrão[2], Elsa Olivetti[1]

[1]Massachusetts Institute of Technology, Cambridge, Massachusetts, United States
[2]IN+ Center for Innovation, Technology and Policy Research, IST, Lisbon, Portugal

Abstract: The urban built environment maintains the alluring prospect of being a source for our future resource needs. This work imagines new local recycling paradigms for concrete and masonry waste within an existing urban environment. Using Lisbon, Portugal as a case study, we proposed three context-specific material recycling scenarios to make use of mineral construction waste generated as the city's aging residential building stock is replaced over the next 30 years. We compared four scenarios – three recycling proposals and standard landfill disposal – in terms of production potential, land use, greenhouse gas emissions, and cost. The results show that from both an environmental and economic standpoint, recycling is not always the optimal solution. The impacts depend not only on the recycling processes and end uses, but also the avoided and added burdens consequent to changes in the existing system. Through this analysis, we identified the limiting factors and potential opportunities for improvement in the current processes of construction material reuse and recycling, in Lisbon and beyond.

Keywords: construction materials, circular economy, recycling, construction and demolition waste (CDW)

Introduction

Construction of buildings and infrastructure in cities accounts for over 35% of total global raw material consumption (Krausmann *et al.*, 2009). The injection of construction materials happens primarily while a city is growing, as the built environment expands to serve the increasing population. In the 20th century, post-World War II urbanization fuelled tremendous growth, resulting in the first wave of major worldwide construction material consumption. As new cities continue to grow over the next century, we will face a second upsurge of material consumption (United Nations Department of Economic and Social Affairs, 2014).

While new construction is projected to grow, the existing building stock is simultaneously aging. Buildings that were constructed during the urban boom of the last century are approaching the end of their useful lifespans. Arguably, these buildings are not old. However, many are not well maintained and this is accelerating their demise. Over two thirds of Europe's housing stock was built after WWII and much of it is in need of major repair and renovation.

When these buildings are ultimately demolished (as projected in the coming decades), most will be sent to landfill (Thomsen, Schultmann and Kohler, 2011). Currently in Europe, roughly 530 million tonnes per year or 2 tonnes per capita of construction and demolition waste (CDW) is generated annually. Individual CDW recycling rates vary from one EU country to another, depending on each country's own regulations. In Denmark, for example, the reported recycling rate is 94% while in Greece and Portugal, the recycling rates are less than

10%. Regardless of the current rate, it is assumed that the amount of construction waste generated will continue to increase, roughly at the same rate as each country's economy (Bio Intelligence Service, 2011).

Instead of seeing the material in existing buildings as waste, is there an opportunity to see it as a reservoir for imminent construction needs? Namely, through deconstruction and recycling. Deconstruction is the methodically planned and highly controlled processes of taking apart a building with the aim of separating components and materials "to avoid down cycling, energy transformation and deposit into landfill as much as possible" (Thomsen, Schultmann and Kohler, 2011). In this work, we imagine the potential for implementing a deconstruction and material recycling scheme in an existing urban context.

Methodology

We imagined three new local recycling schemes for concrete and ceramic waste within Lisbon's existing urban system. The work is organized in three parts: First, we estimated the current material stock and projected material output based on the future end-of-life of the buildings. Second, we envisioned the waste processing scenarios (both the existing disposal scheme and proposed recycling alternatives) for concrete and ceramic waste. Finally, for each of the scenarios we calculated the production potential, landfill requirements, global warming potential, and economic cost.

This work examines a set of existing buildings in Lisbon, Portugal. The area of study consists of seven mixed-use, but primarily residential, neighbourhoods. We considered 750 single-family and multi-family buildings within the site, all constructed between 1946 and 2011. Data pertaining to the buildings was collected as part of the larger MIT Portugal Program's SusCity Project (Sousa Monteiro, Pina and Ferrão, 2015).

Current and Future Material in the Building Stock

The urban building stock is a reservoir for future "extraction." To evaluate the feasibility of this idea, we estimated the material intensity and throughput -- the inputs, outputs, and storage – over the buildings' lifetimes. Then, we probabilistically estimate the end-of-life of the buildings to determine when the embedded materials will become available.

Figure 1: Building archetypes and their material profiles

To estimate the quantity of materials in the existing buildings, we utilized five building archetypes that represent the buildings' architectural qualities and material compositions. The archetypes were developed by Sousa Monteiro, Pina, and Ferrão (2015).

An aging building with little architectural heritage value is especially susceptible to removal, due to real estate and economic market factors (Thomsen, Schultmann and Kohler, 2011). Most of the sample buildings are of this condition, and thus susceptible to this demise. Assuming that the buildings will reach their end-of-life as projected in the coming years, we calculated the concrete and ceramic output every decade from 2020 to 2049. The decadal averages provide a sense of the lower and upper bounds of the potential material output of the site. To calculate the output we employed a Weibull time-to-failure function (Bekker, 1980), adopting the shape and scale parameters from a similar study of US residential building lifetimes (Aktas and Bilec, 2012).

CDW Disposal and Recycling Scenarios

Currently most of the concrete and ceramic waste generated during demolition in Portugal is sent to landfill (Martinho *et al.*, 2015). We assumed the existing condition to be the default waste removal scenario. We envisioned three localized recycling scenarios as alternatives to the default (see Figure 2), each designed to keep the material within the local region to establish a circular economy of construction materials. In each case, a particular end use was specified for the recycled material: road construction, concrete paver block production, and structural concrete in building construction.

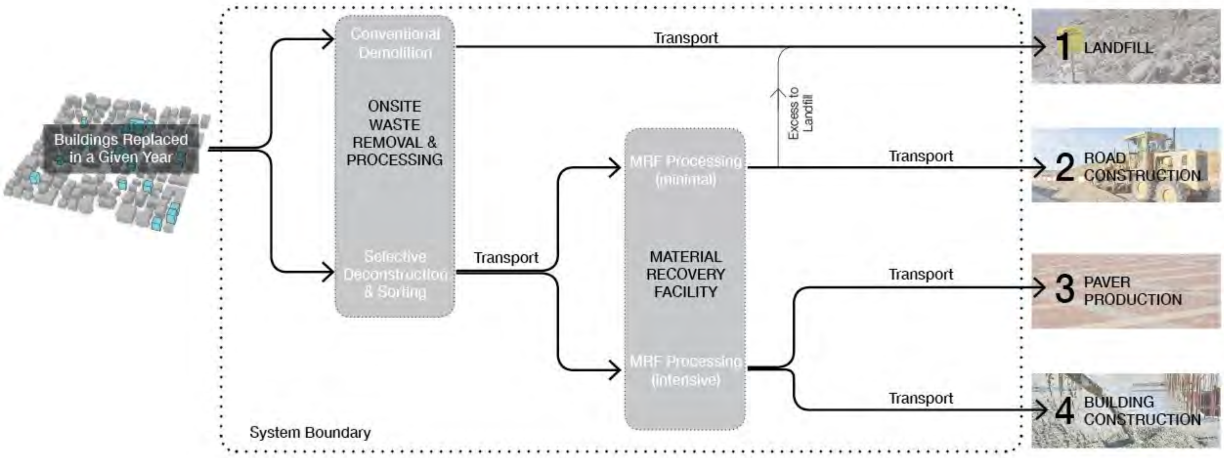

Figure 2: Concrete and ceramic waste processing and recycling scenarios.

The waste processing system includes the demolition or deconstruction of the buildings, the processing of waste into recycled aggregate and all transportation until permanent disposal or sale for use, as shown in Figure 2. The waste processing boundary does not include impacts on the end uses for the recycled aggregate or landfilling. These impacts, henceforth referred to as the *added and avoided impacts*, are considered separately. Transportation, particularly road transport via trucks, has a large impact on the environmental and cost impacts of CDW processing. To make any of the scenarios economically and environmentally viable, we limited the transport distances to reduce the impacts from trucking. Waste processing was limited to a distance of 25 km; landfill and end use drop-off was limited to 50 km; and raw material sourcing was limited to 100 km. The envisioned transportation pathways for each scenario are illustrated in Figure 3.

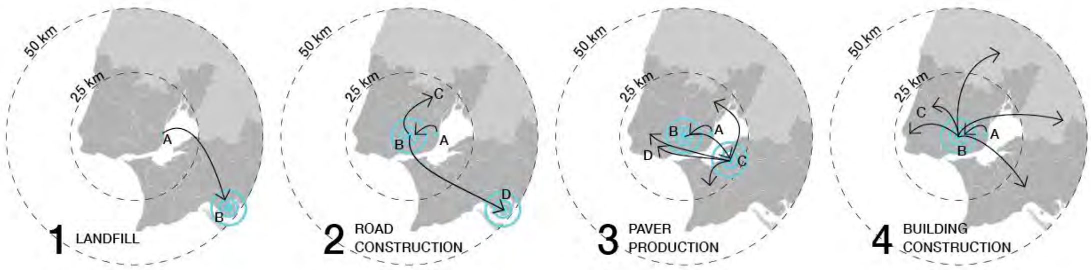

Figure 3: Proposed transportation pathways for the waste processing in the Lisbon metro area.

Calculating the Impact: Production Potential

Concrete and ceramic waste can be processed into recycled aggregate, which feeds a variety of secondary production processes. We considered three possible secondary end uses for the recycled material: *road construction*, *concrete paver block production* and *structural concrete*.

Recycled aggregate is often used as a sub-base layer in road construction. The 2-lane roadway considered in this scenario is based on an assembly proposed by Herrador et al. for an access road in Spain (2012). It consists of a 14cm pavement surface over a 30cm aggregate base layer, over is a second 50cm base of artificial aggregate. The recycled aggregate layer is composed of 75% concrete, 20% asphalt and 5% ceramic material, as per specifications provided by Herrador et al.

Concrete paving blocks used to create pedestrian walkways are a preferred application for recycled aggregate because, like in road construction, it allows for flexibility in quality and purity of the recycled material. The paver production considered in this scenario is based on a pre-cast concrete block proposed by Poon and Lam in their study of aggregate-to-cement ratios for this type of application (2008).

Using recycled aggregate for structural concrete in new buildings is the most appealing of the recycling proposals considered because it is the only truly closed loop system. The concrete mix considered consists of 50% recycled aggregate and 50% raw aggregate, based on Swiss data from Knoeri, Sanye-Mengual, and Althaus (2013). The use of recycled aggregate reduces the structural quality of the concrete, and necessitates a modified concrete mix in order to meet buildings regulations. Specifically, the mix requires an additional 10% cement, 10% fly ash, 50% water, and 30% superplasticizer. This modifications in the mix are considered in the secondary production calculations.

Calculating the Impact: Landfill Area Requirements

Landfill area is required for waste that is not processed and used as recycled aggregate. We assume that in the default demolition scenario, all the waste goes to landfill. In the recycling scenarios, some of the concrete and ceramic waste can go to landfill, as it may not satisfy the recycled aggregate quality required by the secondary uses. We size the landfill requirements based on numbers provided by Butera, Christensen and Astrup (2015): 1500 kg/m3 and 10m height.

Calculating the Impact: Global Warming Potential

Global warming potential (GWP) is a measure of the heat trapped by a greenhouse gas in the atmosphere. It is often measured, as it is in this analysis, over a 100-year period. For each scenario, we added the GWP of each process and activity to get a total GWP value. We employed lifecycle inventory data from the EcoInvent 3 database using SimaPro and the IMPACT 2002+ impact assessment method (PRe Sustainability, 2014; Wernet *et al.*, 2016).

Calculating the Impact: Costs

We estimated each scenario's overall cost based on recycling and waste processing industry data for Portugal (Coelho and de Brito, 2011; Coelho and De Brito, 2013). The cost includes all processes that are within the waste processing system boundary, from demolition to delivery of the recycled aggregate to the end use. For the three recycling scenarios, we also considered the potential earnings from selling the material. It is assumed that the concrete portion of recycled aggregate is sold at a rate of €2.76/tonne while the brick waste is given away at no cost (Coelho and de Brito, 2013).

Results

Production Potential

We assumed that 90% of the concrete and ceramic waste coming out of the sample buildings goes to the material recovery facility (MRF) for processing (and the remaining 10% is lost in onsite processing). This amounts to 19,910 tonnes per year recovered; of which, roughly 60% is concrete and 40% is ceramic. We assumed that, once in the MRF, 68% of the waste material is turned into recycled aggregate and 32% is lost as fines (Weil, Jeske and Schebek, 2006). Based on the material output from the MRF, we calculate the production potential of each recycling scheme:

In scenario 2, we estimated that annually 8,000 tonnes per of concrete aggregate and 5,500 tonnes of ceramic waste is available for use in the road. The production is limited by the amount of recycled concrete aggregate available, therefore only 500 tonnes of the ceramic waste is utilized. The remaining 5,000 tonnes of ceramic is assumed to go to landfill. Based on the amount of concrete recycled aggregate supply, approximately 1.5 to 2 km of new roadway can be constructed. Using the recycled aggregate results in 12,000 tonnes per year of avoided natural aggregate use.

In scenario 3, we assumed that 100% of concrete and ceramic recycled material, or 13,500 tonne per year, is used for paver production. The recycled material provides enough aggregate to produce 5.8 million paver blocks, enough to pave 35 to 40 km of 3m-wide pedestrian sidewalks. Using the recycled aggregate results in the avoided use of roughly 14,000 tonnes per year of raw aggregate.

In scenario 4, we assumed 100% of the concrete and ceramic recycled material is used as aggregate. This quantity can replace half of the natural aggregate required for the structural concrete, avoiding 23,700 tonnes of raw limestone sourcing per year. The mass of avoided raw material is greater than the mass of recycled aggregate used because of the difference in densities: 1890 kg/m3 for natural aggregate versus 1374 kg/m3 for recycled aggregate. The recycled aggregate coming from the buildings stock supplies enough material for roughly 19,700 m3 of structural concrete per year, enough to construct about 12 multi-family apartment buildings.

Landfill Area Requirements

In scenario 1, we assumed that all of the waste coming out of the buildings goes to landfill requiring a total area of 40,000 m^2 for waste over the 30-year period. In scenario 2, the road sub-base layer requires a mix of 75% concrete, 20% asphalt and 5% ceramic aggregate. Roughly 5,000 tonnes per year of ceramic aggregate is unused and assumed to be disposed in landfill, requiring a total area of 10,000 m^2 over the 30-year period. In both scenario 1 and 2, the landfill area was sized for the material output over the full 30-year study period (2020-

2049), as CDW landfills require long-term planning and land allocation. In scenarios 3 and 4, all of the concrete and ceramic-based recycled aggregate is used, thus there is no material sent to landfill. Material that is lost as fines during the recycled aggregate production process in MRF was excluded from the estimates in all cases.

Global Warming Potential

Global warming potential (GWP) results are presented first for the primary system (i.e direct impacts) and separately for the added and avoided impacts (Figure 4). For the primary system alone, scenario 1 resulted in the least amount of GWP. This is expected since the other scenarios have added activities and transportation associated with recycling. This is particularly true for scenarios 3 and 4, due to the added processing and transportation needed for a higher grade recycled aggregate. This result is in line with other similar studies of CDW recycling (Blengini, 2009).

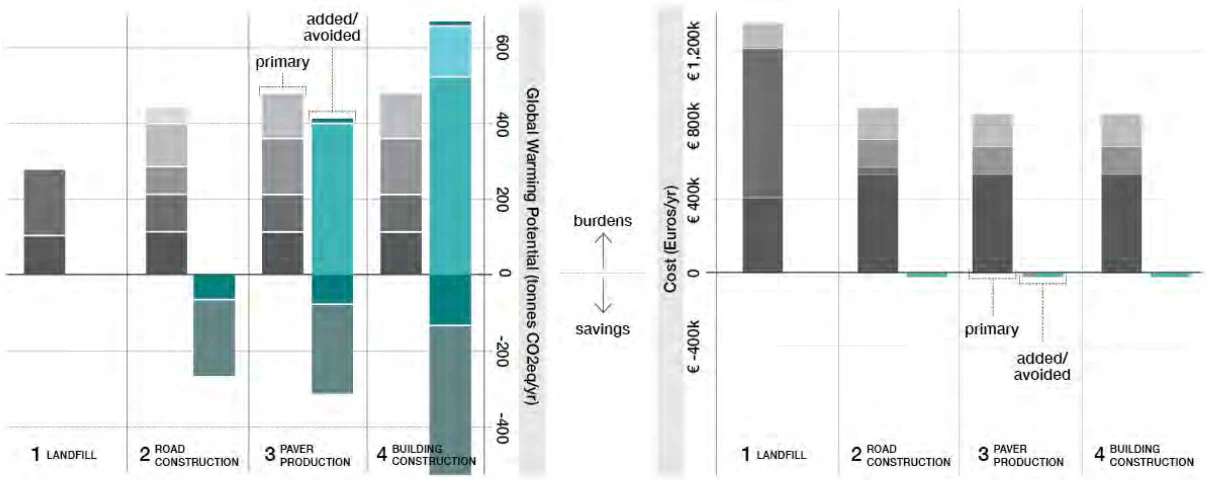

Figure 4: Global warming potential (tonnes CO2 eq per year) and costs (euros per year) for each process. The direct impacts in the system boundary are in grey; the added and avoided impacts of the associated end use processes are in color. Positive values are GWP/Euro burdens or “costs,” negative values are savings.

The changes in the end uses resulting from the application of the recycled aggregate are significant and, if allocated to this system, can influence the GWP results greatly. In all recycling scenarios, there is a negative GWP for avoiding the use of natural aggregate. At the same time, in scenarios 3 and 4 there is an added impact for the increased use of cement and other materials to make up for the loss in strength of the concrete. Due to the high carbon intensity of cement production, the added GWP from the increased use of cement is about as much as the whole waste recovery and recycling process itself.

The added and avoided activities in the end uses could be alternatively allocated to the secondary processes. If this were the case, then these impacts would *not* be included in the analysis of these scenarios. Whether the impacts are included or not, it is useful to see the magnitude of environmental consequences resulting from the changes required in the end use processes relative to the waste recycling processes.

Costs

The costs include all processes within the waste processing system boundary, from demolition to delivery of the recycled aggregate to the secondary end use. For the three recycling scenarios, the potential earnings from selling the material were also considered. All three recycling scenarios have lower net cost than the disposal case primarily due to the high landfill tipping fees (Figure 4). The tipping fee is assumed to be €41/tonne for mixed CDW as per Portuguese industry data (Coelho and de Brito, 2011). The results show that while the recycling schemes have added processing and transport activities, the high fee for disposing the material in landfill results in roughly 50% increase in cost over any of the recycling scenarios. It should be noted that the cost analysis does not consider changes in the cost of the secondary end use production.

Results Summary and Analysis

	1 LANDFILL	2 ROAD CONSTRUCTION	3 PAVER PRODUCTION	4 BUILDING CONSTRUCTION
Production Potential (variable)	-	2 km new roads per year	35 km new sidewalks per year	12 new apartment buildings per year
Landfill Area (m2)	40,000 m2 for 30 year period	10,000 m2 for 30 year period	-	-
Global Warming Potential (tonnes CO2eq/yr)	274 (+/- 84)	174 (+/- 230)	572 (+/- 221)	616 (+/- 302)
Cost (euros/yr)	€ 1,358,000 (+/-67,000)	€ 885,000 (+/-88,000)	€ 845,000 (+/-88,000)	€ 845,000 (+/-88,000)

Figure 5: Summary of results for the four scenarios.

There is no scenario that is advantageous across all categories, as illustrated in Figure 5. In the three recycling scenarios, waste has a production value and contributes to the creation of something new (either roads, pedestrian pathways or buildings). The societal value of each end use depends largely on the local demand for the product in question. The environmental impacts – measured in terms of GWP (a global impact) and land use for landfill (a local impact) – have an inverse correlation. Namely, the recycling scenarios require additional processing and transportation, increasing the overall GWP; at the same time, using the material means that less waste is sent to landfill. Lastly, the landfill disposal scenario costs over 50% more than all of the recycling scenarios. This is due to the high landfill tipping fees. There is a minor cost distinction between the recycling proposals themselves, as the waste processing to create the aggregate is similar in each case. However, this cost analysis does not consider additional or avoided expenses in the secondary production processes. In summary, based on the four impacts considered, there is no clear winning scenario. The preferred option is in large part dependent on the local needs, economic conditions and environmental priorities.

Conclusion

Can we utilize the materials embedded in our existing buildings as a resource to feed the next generation of cities? In this work, we examined this question by analysing three site-specific schemes to locally recycle concrete and ceramic waste. We considered the impacts of each scheme in terms of production potential, land use, global warming potential, and cost. The results show that, from both an environmental and cost standpoint, the circular material paradigm is not always the optimal solution. The impacts depend not only on the recycling processes and end uses, but also the avoided and added burdens consequent to changes in the existing system. The results highlight the need for a nuanced approach to the topic of waste management and resource recovery. It is often the case that recycling is an environmentally preferable alternative to landfilling. However, as shown in the results of this analysis, there are exceptions. Ultimately, we must develop more thoughtful, efficient, and long-term holistic solutions for material use and reuse in construction.

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Vernacular Architecture: Advocating Volcanic Stone Construction as a Viable Alternative to Fired Brick in Mountainous Areas of Southwestern Uganda

Peter Wasswa[1] , Achilles Ahimbisibwe[1], Alex Ndibwami[1]

[1] Faculty of the Built Environment. Uganda Martyrs University, P.O. Box 5498 Kampala, Uganda. aahimbisibwe@umu.ac.ug, andibwami@umu.ac.ug, wasswapw@gmail.com

Abstract: Natural stone possesses physical properties suited for structural walling, yet in Uganda it is habitually specified for its aesthetic finish. Kisoro, Fort portal, and Bushenyi are naturally endowed with abundant volcanic stone, yet residents still opt for brick walling despite the poor soils in the area, which produce low quality bricks. In comparison to Compressed Earth Block (CEB) and Compressed Soil Block (CSB), stone barely features as a sustainable walling option. Industry, economics and Infrastructure development have each played a significant role to interrupt the success of sustainable development particularly with regards to fired brick. Swamp destruction, air pollution, and unregulated indiscriminate deforestation linked to fired brick production are entirely ignored. Uganda loses 3% of its forest cover every year raising carbon emissions in 2013 to 0.134 tons per capita. Efforts to avail more environmental, ecofriendly and socially relevant alternatives to fired brick have done little critical interrogation on case-by-case basis for rural communities around the country. This paper presents volcanic stone as a viable walling material in areas where it is abundant.

Keywords: Vernacular, Stone Construction, Sustainable development

Introduction

Natural stone possesses physical properties suited for structural walling however; in Uganda it is habitually specified for its aesthetic finish *(floor surfacing and wall cladding)*. In comparison to Compressed Earth Block (CEB) and Compressed Soil Blocks (CSB), stone has not been explored as a potential front-runner among sustainable walling alternatives. Kisoro, Fort Portal, and Bushenyi are endowed with abundant volcanic stone, however, yet residents still opt for brick walling despite the poor soils in the area, which produce low quality bricks. While developing countries like Uganda struggle to meets the Sustainable Development Goals, little is being done to empower local communities to meet their own local aspirations. Industry, economics and urban Infrastructure development have each played a significant role to interrupt the progress of sustainable development particularly with regards to fired brick. The swamp degradation, air pollution, and unregulated indiscriminate deforestation linked to fired brick production have all been ignored to favour what is considered an inexpensive walling material. According to (NEMA 2002: 122), Uganda loses 3% of its forest cover every year raising carbon emissions in 2013 to 0.134 tons per capita. This raise in emissions can be traced back to the triumph of fired brick. Efforts to interrogate environmentally, eco-friendly and socially conscious alternatives to fired brick require a critical case-by-case approach to distinctive rural communities around the country. This paper, presents volcanic stone as a viable walling material in areas where it is abundant.

The use of stone in the construction is not completely alien to this context. According to Nnamdi (1997), stone construction in Africa dates back to over 10,000 years ago. In fact, Shadmon (1996) writes that Stone was used for construction way before man ever started using metallic tools. Stone construction in Africa was popular in hilly parts of Africa creating what was known as the "hill style", Nnamdi (1997). More recently, residents in the hilly areas of Bunyaruguru and Kasese have constructed and actually live in stone buildings as shown in *Figure 1*. In parts of Kabale stone construction is evident in their stone garden perimeter walls, and stone cooking fireplaces.

Figure 1: Stone Cottage in Fort Portal and abundant stone in south western Uganda

Fired brick is not indigenous to Uganda's material palette, in fact it was never used, at least not until a century ago, when the biggest Cathedrals were constructed at Namirembe and Rubaga (Moon, 1994). The complexity of the then imported Gothic and Romanesque style cathedrals could not be achieved using the popular vernacular materials of the time like reeds, mud and thatch. Therefore, the British and French architects resorted to a more structurally capable material; the fired clay brick (Olweny, 2007). Banking on the lush forest environment that existed at the time and swamp clay around Lake Victoria, the stature and magnificent of these cathedrals gave rise to a wave of change in Uganda's construction industry. Industry demand is consistently impacting Uganda's forest cover. World Bank (2015) estimates that Uganda's formerly lush forest cover is now a mere 8.6% of the country's total land area. This massive deforestation is to a large extent linked to fired brick production. An independent student in the Nkozi village found that on average its takes over 9 tonnes of wood fuel to fire a medium sized kiln for 20,000 Bricks (Ahimbisibwe et al, 2016). Further, artisans keep the firing period and temperature low to save on fuel (*which is increasingly harder to come by*), this in turn results in low quality bricks up to 45% of the entire production. More bricks are lost when it rains or on nights a cool breeze. Naturally occurring forests as well as recently planted forests are being cut down for wood to fuel brick production as well as to serve as construction timbers such as formwork and other structural supports. However, it's not just forests that have suffered at the expense of the growing popularity of fired clay brick in the country. Swamps too are being destroyed and depleted of clay. According to SSA: UHSNET (2015), good clay is becoming increasingly scarce in Uganda. This has crippled the already struggling pottery industry in Uganda.

Worse still, the local brick industry is highly unstandardized and because of this there is an inconsistent quality of bricks most of which are irregular. Further, some bricks are made from poor quality soils (locally know as *kifufu*) and are significantly weaker than the ignorant public expects. Irregularities in brick configuration have led to the wasteful use of mortar as the masons attempt to deliver straighter walls. Additionally, weaker bricks contribute to heaps of waste noticed on numerous construction sites as in *Figure 2*. The cost of brick construction is even higher in the mountainous areas of Southwestern Uganda where good clay soils hardly exist. Brick are transported large distances to service these areas; further increasing the economic and environmental cost of construction. Brick transportation in the popular diesel trucks used in Uganda countries for partly loaded, small to medium gasoline trucks over rough roads could consume as much as 5MJ/tonne for every kilometre (Fraser et al, 1995). Transportation delivers an avoidable carbon load of up to 0.0741 $KgCO_2$ per kilometre (Quashning, 2016).



Figure 2: From Left to Right, Fired Brick waste at Kiln, in Construction and heaps left over after construction

World Bank estimated that by 2012, 19.5% of the country's population was below the poverty line, majority living in rural communities of Uganda such as those that make up most of the mountainous southwestern parts of the country. As a consequence, reducing the cost of construction is crucial for the success of vital infrastructure developed such as housing. "The cost of an average home mortgage in Uganda is about $30,000" Muhumuza (2016). However, according to the World Bank development indicators (2016), Uganda's Gross National Income is $670. On a monthly basis, that is an average of $56. This means that on average a Ugandan committing up wards of 30% of their annual income to service a mortgage, would require 144 years for one to pay off the loan. These sums are inflated when interest is compounded. This indicates that even a middle-class Ugandan would need to spend well over 50% of their income to afford decent housing. Yet still, low cost housing in Uganda is considered by Ministry of Lands, Housing and Urban development, to be that which doesn't exceed more than 30% of the homeowner's income (Muhumuza, 2016).

Unfortunately, architects in practice are not helping the situation. Most architects in the country persistently avoid rural commissions because few, if any, people there can afford their professional fees. As a consequence, the low-skill level *"Fundis"* and draftspersons that take on these rural projects generally work with a *"standard"* brick palette as taught in technical schools. Potentially viable materials and construction techniques in rural societies are not being unexplored for their economic and environmental merit.

However, involvement of Ugandan architects in rural construction projects is also unlikely to yield any appreciation for those local materials since according Olweny (2006), most architecture schools in Uganda are making no efforts to involve technology as an important aspect of architectural design. This has resulted in minimal efforts by architects to research and creatively come up with new ways to improve and use vernacular materials. Moreover, even the schools that do incorporate technology in the student's design process, have their efforts let down when students go into the field and become negatively influenced by senior architects with contrary education, field and construction experience. The result of this is architecture that is not primarily informed by its context. No wonder, foreign architects undertake most contextually responsive commissions in the country.

Another factor at play here is the existence of urban-rural links across the country. According to Odongo (1977), when people migrating from rural to urban areas succeed in Urban areas, they go back to their rural homelands and set up big houses as a sign of their success. These houses are in most cases copies of similar houses in urban areas built mostly with fired brick. Locals then begin to associate not only clay brick but also other wasteful materials to wealth and prestige and therefore strive to liken their houses to the town brick house, giving no chance to other viable local materials or construction techniques. This further creates an industry of local artisans who develop their skillset exclusively to support the "fired brick" market. Furthermore, low levels of income in rural areas cannot allow these artisans to develop skills in constructing with local materials and construction techniques which are not in demand.

There are three dormant volcanoes in southwestern Uganda, and these include: Muhavura, Bufumbira and Fort Portal. According to Shadmon (1996), in the eruption of a volcano, as hot Larva reaches the earth's surface, it quickly cools down, forming crystals of igneous volcanic rock. Some of these rocks include andsite, basalts, purnice, and rthyolite. It is important to note that any one of these stones have a higher compressive strength than the popular fired brick. Take for example basaltic rock that is most abundant in these areas, has an uniaxial compressive strength ranging between 12-63 Mpa, Schultz (2012). Which is higher compared to the average compressive strength of fired brick that ranges between 5-10 Mpa.

An interview held with the locals revealed the residents' general perception that stone construction is expensive. The locals even refer to it as the *rich man's material*. According to the locals, stone construction requires a lot more sand and cement mortar than fired brick. Also, due to low popularity of the material, skilled masons in the area are rare and expensive. Interviewed residents revealed that the construction process too takes a long owing to longer durations required to dry the huge chunks of mortar. The delicate process of laying the uneven stone to form regular walls, also contributes to the prolonged construction process.

However, stone has always been used as construction materials in the area. The residents say that before the popularity of brick in the area, vernacular architecture was constructed using mud and wattle like in other indigenous communities of Uganda. However, unlike in other areas, people in Kisoro added small volcanic stones to the mud to create firmer walls. The walls were then finished with chalkstone dissolved in water to create a smooth surface. Today, there are few stone buildings in the area mostly owned by the rich. The difference being that the wealthy use sand and cement, yet the rest use mud mortar. However, the result is not sturdy and for this reason, some residents in search for better quality buildings opt for fired brick rather use stone with mud mortar.

Interviews revealed a latent optimism towards stone construction. However, mortar was presented as the major hindrance to stone construction, cement and sand mortar is too expensive and mud mortar is low in quality. The solution to this is dry stone construction. Dry stone construction involves careful selection of irregular stone to be stack together without slipping, forming a firm freestanding wall. Dry stonewalls are typically wider at the base and are much narrower higher up. According to Gray (2015), dry stone structures gain strength from the weight of stone pushing inwards and settling, causing the stone to lock together forming a stronger structure. This type of construction does not require any special tools or materials. However, it requires a skilled craftsman to choose and place the stone together. This type of stone construction has so far succeeded in Kenya mainly in the residential sector mainly due to durability, low construction costs and the simple structures of residential buildings (Ochola, 2016). Ochola adds that volcanic stone has an outstanding ability to retain heat. Heat retention is of great advantage in parts of southwestern Uganda where temperatures fall as low as 5 °C.

One good practice example in a similar context is Butaro hospital by MASS design group architects located in Butaro, Rwanda just a few kilometers from Kisoro with similar climate, terrain and abundance in volcanic rock. This project made use of the local volcanic rock, but also successfully convinced the society through the quality of the physical structure, that there is potential in this long-ignored material. With the society convinced, a new industry of stone dressing, marketing and construction has been able to kick off in Butaro, creating jobs that otherwise didn't exist as Benimana (2016) explains. Similarly, The artisans who hand-crush stones for aggregates in Southwestern Uganda can be further commissioned to shape volcanic stone to more regular blocks that can be assembled with less mortar. Further, in this same context, there is an existing trade of hand-crushed stones for construction aggregates. Stone crushers stand a chance to make additional income from stone dressing like their counter parts in neighbouring Kenya as shown in *Figure 3*.

Figure 3: Ugandan students learning how to dress soft Stone from an artisan in Machakos, Kenya.

It all comes down to equipping communities with the necessary knowledge and skilling a few artisans to enable them better evaluate their decisions. If architects with projects in rural areas made an effort to understand and develop the available local materials and construction techniques, and most importantly, involve the locals in this process, community transformation will then be possible. Schools of architecture, too, need to educate built environment professionals to be more open-minded and to take pride in the heritage of this country, and the materials and opportunities that our context has to offer. This can be achieved by questioning how we build and who builds if we are to transform rural communities all over the world.

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Overheating

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Thermal comfort and overheating investigations on a large-scale Passivhaus affordable housing scheme

Andrea Botti[1]

[1] Centre for Environment and Sustainability, Faculty of Engineering and Physical Sciences, University of Surrey, Guildford, UK, a.botti@surrey.ac.uk
PRP, Lindsey Street, London, UK, a.botti@prp-co.uk

Abstract: The uptake of the Passivhaus standard has rapidly increased in the UK during the recent years, in line with the improvements in the energy efficiency standards for new dwellings. This paper builds upon a recently completed post-occupancy study for a Passivhaus-certified large-scale affordable housing development, specifically focusing on summer thermal comfort. Assumptions and predictions of overheating risk made at the design stage are analysed and compared with the indoor temperatures measured during summer 2015. In this study, interviews and questionnaires are overlaid with quantitative data in order to explore occupants' comfort perception and improve the understanding of the inter-relationships between aspects of building design, occupant behaviour and the risk of overheating. The analyses showed a high frequency of overheating, diverging significantly from the estimates made using the PHPP tool. This is due to a combination of factors, such as higher internal heat gains arising from higher occupant density and usage of internal appliances and, in some cases, insufficient reliance on natural ventilation to purge excess heat. Given the difficulty in predicting in-use occupancy patterns at the design stage, a more robust design strategy is recommended, which could include measures to minimise summer overheating and future-proofing against a changing climate.

Keywords: passivhaus, PHPP, overheating, monitoring, post-occupancy-evaluation

Introduction

There has been an increasing up-take of housing schemes built to Passivhaus standards in recent years, in line with Government policy trends that have encouraged improvements in the energy efficiency standards for new-build developments. In an effort to tackle fuel poverty, which still affects 10.6% of English households (DECC, 2016), social housing developers are expected to be the frontrunner for building energy efficient for their social renters (McManus et al., 2010).

Buildings designed and built to Passivhaus standards are considered to be highly energy efficient, due to a highly insulated and airtight building envelope, as well as to the optimisation of passive solar gains and heat generated from building occupants (McLeod et al., 2011). While these measures can significantly reduce the energy use as well as improve thermal comfort in the winter months, a growing body of literature suggests that unintended consequences may arise during the summer months, contributing to the risk of indoor overheating (Dengel & Swainson, 2012; McLeod et al., 2013; Jones et al., 2016).

Despite the recent adoption of the Passivhaus standard in the UK (Passivhaus Trust, 2016), a growing number of research studies are focusing on the overheating assessment of Passivhaus buildings, by means of both thermal simulation modelling and of in-use data monitoring (McLeod et al., 2013; Sameni et al., 2015). The risk of summertime overheating has been documented for Passivhaus buildings in Northern Europe (Larsen & Jensen, 2011), and it has the potential to be severe in the UK as a result of climate change (Jenkins et al., 2009). For Passivhaus built in urban locations, McLeod et al. (2013) warned that active cooling may become a requirement in the near future, unless the minimisation of future overheating risk becomes a key design objective.

In order to obtain Passivhaus certification, designers have to consider summer thermal comfort and are required to provide evidence the risk of overheating is minimised. However, the assumptions made in the PassivHaus Planning Package (PHPP) design tool are often standardised, thus they may not accurately reflect the conditions observed in reality. Opening windows for purge ventilation may be limited or not at all possible in urban locations. Furthermore for certain types of occupancy, such as social housing tenants in the UK, research has suggested that occupant density and internal heat gains may be significantly higher than the standardised assumptions included in the PHPP (McLeod et al., 2013). As it has emerged in the recent years, building overheating is a complex issue and there is a lack of conclusive evidence on how the risk predictions produced using simplified methodologies compare to the in-use performance (ZCH, 2015).

Methodology

Case study

This paper builds upon a recently completed POE project carried out for an affordable housing scheme, located in the London Borough of Havering and completed in 2015. The scheme is one of the first large-scale 100% affordable Passivhaus-certified housing developments in the UK, with a total of 51 dwellings, comprising one-bedroom and two-bedroom flats, and three-bedroom and four-bedroom terraced houses.

The study involved monitoring a sample of 9 homes during the first year of occupancy (Table 1), in order to gain an understanding of residents' experiences and behaviour. Both quantitative and qualitative methods were used, where environmental data was collected from the main rooms and questionnaires were prepared for the purpose of conducting in-depth interviews with the residents. By overlaying the two information sets, a rounded understanding of the relationship between building performance and occupant behaviour was gained, including how far different behavioural patterns deviated from the typical design assumptions. This paper narrows down the broad focus of the POE project to look more specifically at summer-time thermal comfort. The extent of indoor overheating is assessed for monitored temperatures and compared to the predictions made at the design stage, allowing to quantify the performance gap and to identify the main causes for it.

Table 1. Total units and sample units selected for the POE study

Block	Unit types	Total no of units	No units in POE study	Short names
Block A	1B, 2B flats	16	4	A08, A10, A11, A16
Block B	4B house	13	0	
Block C	3B house	8	2	C01, C06
Block D	4B house	13	3	D11, D12, D14

Thermal comfort assessment criteria

Buildings seeking to achieve Passivhaus standard have to be modelled using the PHPP design tool developed by the Passivhaus Institut (PHI). For summer thermal comfort, the PHPP sets out a maximum temperature threshold, intended as a comfort limit, and using steady-state calculations it predicts the frequency which temperatures are expected to exceed it. Such overheating risk is expressed as a percentage of the occupied year, which for a dwelling is taken as 365 days (Passivhaus Institut, 2014).

$$T > 25°\text{C } (= T_{max})\ for\ more\ than\ 10\%\ annual\ occupied\ hours$$

While meeting the 10% target is mandatory in order to achieve the Passivhaus certification, the guidelines recommend that the frequency of overheating does not exceed 5% in order to guarantee high summer comfort in a changing climate (McLeod et al., 2011).

Review of the design assumptions in the PHPP

While a comprehensive in-depth review of the PHPP as a design tool is outside the scope of this paper, the present study follows two lines of investigation:

a) how different are the risk estimates made for the different unit types at the design stage, and why;
b) how far the risk estimates are reliant on assumptions of in-use occupant behaviour.

As such, for the purpose of this study only the factors leading to different estimates are reported (Table 2). In terms of heat gains, this means solar gains resulting from different block orientations and internal gains from different assumptions on household size. With respect to heat losses, including natural ventilation by means of window opening.

Table 2. Factors defining heat gains and losses during the summer as calculated through the PHPP tool (v8.5)

PHPP v8.5				Heat Gains			Heat Losses		
				Solar Aperture (for solar gains)		Int. heat gains	Ventilation (ach)		
	TFA (m^2)	No units	No occupants	total (m^2)	(m^2/ m^3)	Specific power (W/m^2)	via MVHR	Via windows	OH Risk
Block A	1311	17	37.5	35.6	0.03	2.9	0.34	0.0	2.6%
Block C	639	8	18.3	22.5	0.04	2.3	0.30	0.1	2.3%
Block D	1476	13	42.2	68.4	0.05	3.5	0.40	0.2	8.3%

Quantitative data collection: monitoring equipment and external weather

Monitoring of indoor environmental conditions was carried out using HOBO UX100-003 Temp/RH 3.5% data loggers to record indoor temperature and relative humidity (with ±0.2°C accuracy) and HOBO UX90-001 State/Pulse/Event to record window opening. The UX100-003 loggers were calibrated in an indoor environment, revealing a ±0.15°C difference which was deemed acceptable for the purpose of the study. The UX100-003 loggers were placed on top of door frames, away from sight, direct sunlight and active heat sources and data was recorded in 15-minute intervals. HOBO UX90-001 were fixed onto window frames.

The focus period chosen for this paper ranges from 21st June to 21st September 2015, herein referred to as ‘summer 2015’. During this period a short ‘hot-spell’ was experienced, from 30th June to 2nd July, with temperatures exceeding 30˚C on two days.

External weather data was obtained from Gravesend-Broadness weather station, using the MIDAS data archive system (Met Office, 2012). A comparison between the monthly weather data used in the PHPP calculations with mean monthly values calculated for the Gravesend-Broadness weather station (Table 3) shows no significant difference other than for the month of July, partly due to the hot spell. While it is likely that had an impact on the 25C exceedance, this assessment has not been the focus of this research, as all units were impacted in a similar manner.

Table 3. Monthly data for design weather, compared with mean values recorded during summer 2015

Location / type of data	Distance from site	Jun	Jul	Aug	Sep
Hemsby (East Anglia) / generated from historical data	~100 miles	15.2	16.7	17.4	14.9
Gravesend-Broadness (Kent) / calculated from data collected during summer 2015	~10 miles	15.9	18.1	17.7	13.6

Qualitative data: occupant perception and behaviour

The broader study relied on questionnaires and one-to-one interview, including both ranking and open questions, to collect background information about the household composition, occupants' background, perceptions of their thermal environment and interaction with it. For the purpose of this paper, an extract of the questionnaires for the summer period was considered, particularly the section exploring thermal comfort perception, when asked "H*ow has your home been over the summer?"* participants could choose from: "*comfortable"*, "*sometimes too hot"*, "*always too hot"*. As for window opening behaviour, when asked "*When did you open windows?*" they could indicate "*never*", "*out of habit*", "*when too warm*", "*all day*" for day-time and "*never*" and "*always*" for night-time.

Results

One of the early findings of the POE project was the discrepancy between the standard occupancy assumptions and those actually observed, in terms of both size of households and occupancy patterns. Table 4 provides a summary of such patterns, indicating the typical pattern for the adult (block A) or the adults (blocks C, D) for each households.

Table 4. Comparison between actual size of households and PHPP assumptions

		Household size		Occupancy pattern	
Block	Unit	Actual	Assumed	Actual	Assumed
Block A	A08	2	2.2	works part-time	standard
	A10	2		home most days	
	A11	2		works part-time	
	A16	2		works part-time	
Block C	C01	4	2.3	both home most days	standard
	C06	5		partner home most days	
Block D	D11	6	3.2	both home most days	standard
	D12	5		both home most days	
	D14	5		both work full-time	

Internal temperatures were very high during the whole period, with median often above 25°C, as shown in Figure 1. However, different building unit types showed different temperature distributions: most notably, much greater ambient temperatures swings were observed in the houses' (block C and D) if compared to the flats (block A), which were mostly ranging between 24°C and 26°C.

The occurrence of overheating for the summer period, i.e. a 25°C exceedance expressed as a percentage of annual occupied hours is shown in Figure 2. The chart provides a comparison between the predicted risk of overheating (black bar), expressed as a summary figure for a whole block and calculated using monthly average values, and the much more granular data - logged sub-hourly - for individual rooms in each unit. This approach can reveal the limitations of using simplified tool when trying to capture a complex phenomenon such as indoor overheating.

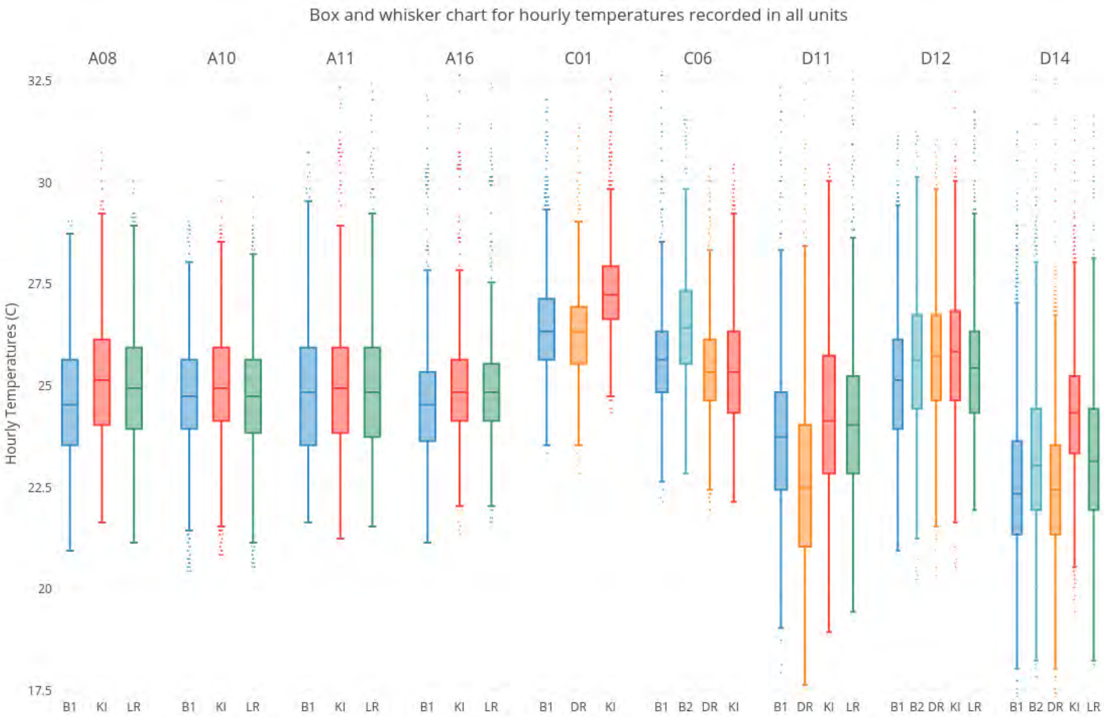

Figure 1. Box and whisker chart of indoor temperature observed during summer 2015, colour coded based on room type (i.e. blue=bedroom1, cyan=bedroom2, red=kitchen, yellow=dining room, green=living room)

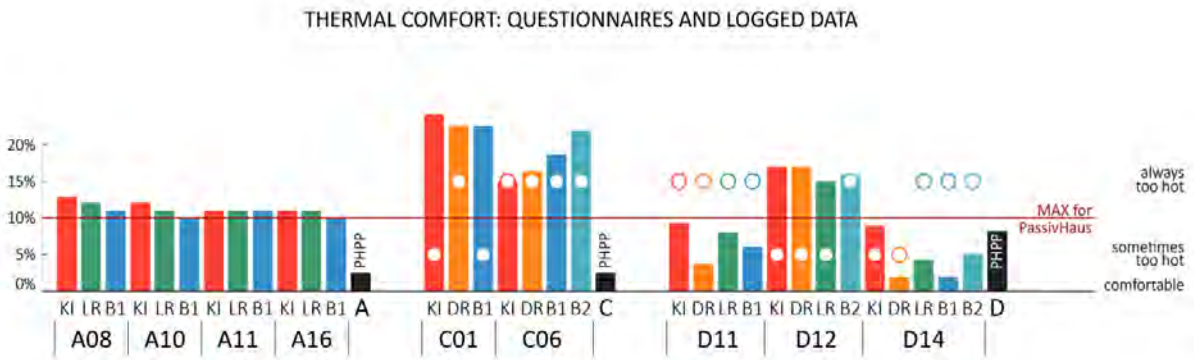

Figure 2. Number of occupied hours above 25 ºC for all monitored rooms, expressed as a percentage of total occupied hours during the period (right) as well as for a whole year (left).

While all flats (block A) failed the overheating criterion and greatly exceeded the PHPP predictions, their thermal performance was fairly homogeneous. On the other hand, a notable difference could be observed for the houses, suggesting the impact of occupants' behaviour, both in terms of internal heat gains and natural ventilation. Previous research has highlighted how using fixed W/m^2 internal gain figures for each building type, while convenient as a design aid, can lead to anomalies at extremes of building size and occupancy (Grant & Clarke, 2014). Given assumed internal gains are largely proportional to occupancy, the discrepancy between those and the actual figures is a key factor behind the gap displayed in Figure 2.

Window opening behaviour

An indication of the impact of building occupancy on thermal performance for all units was obtained by combining residents feedback included in questionnaires with window opening captured by data loggers. This allowed a reciprocal validation of the two data sets. As shown in Figure 3, data showed heavy reliance on natural ventilation for household D11, where windows were mostly open at day and night and, to a lesser degree for D14, where the rooms at ground floor level where only ventilated during the day and rooms at the upper floors both at day and night. C01 and C06 opened windows during the day and kept them closed at night, whereas D12 only appeared to be opening those in the main bedroom (B2).

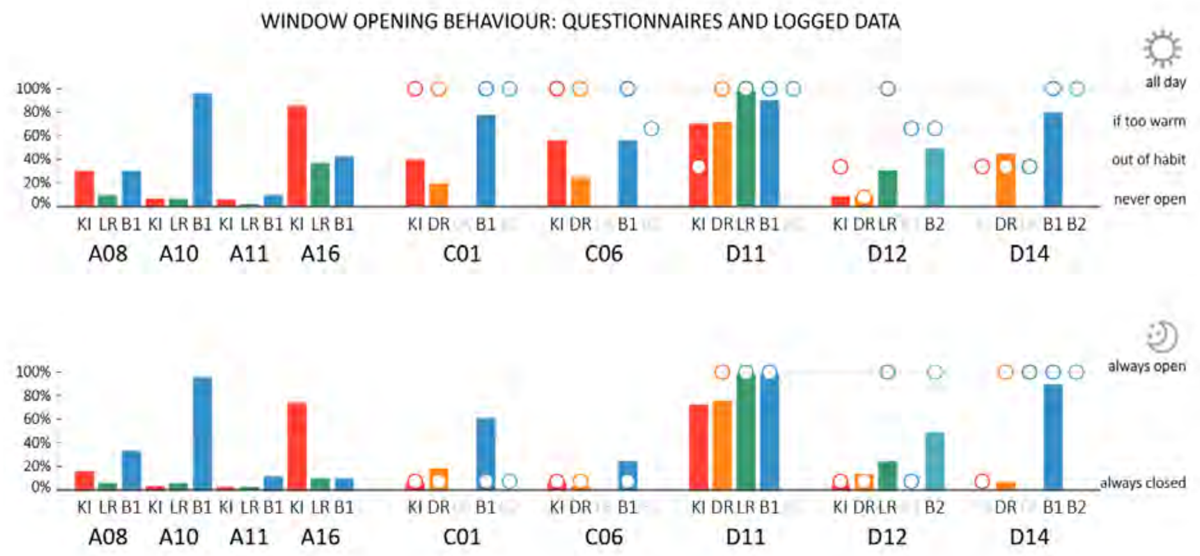

Figure 3. Reponses from residents' questionnaires (circles) and monitored data (bars) for window opening during day-time (above) and night-time (below)

Discussion

Discrepancies were found between different properties under study, and between measured and predicted summer thermal performance for nearly all of these. This was due to a combination of design aspects and, most crucially, occupant-related factors that were not predicted – or could not be predicted – at the design stage.

Solar shading

The estimated solar gains, as indicated in Table 2, where much greater for block D than block C (ca.133 vs 91 kWh daily solar load). However, it was observed that properties in block C made little or no use of internal shading (e.g. internal curtains or blinds), even during the warmest days, as opposed to households D11 and D14, were dark curtains were used. The discrepancy between different households in block A was less noticeable, given they all benefitted from solar shading provided by balconies on the south façade. In this regard, occupant behaviour could help justify the different performance observed among the households, as no discrepancy with the PHPP estimates was found.

Internal heat gains

A significant difference was found between what assumed at the design stage and what observed in reality. While the PHPP assumed values for the houses in block C (2.3 W/m^2) to be nearly 35% than those in block D (3.5 W/m^2), information gathered in one-to-one interviews suggested this was not the case. C06 made extensive use of energy-intensive plasma screens throughout the summer, to watch TV on the main living room and to play games console in bedroom2. D12 and C01 also made an intense usage of appliances during the summer period, running the washing machine and the dishwasher every day (up to 3 times/day for C01).

Ventilation via window opening

A dramatic difference was found between different properties with regards to natural ventilation, as shown in Figure 3. In one-to-one interviews, residents were asked to further comment the data collected from window loggers helping to uncover scenarios where ventilation rates were significantly reduced, which were not captured by window loggers. This revealed how household C01 had often been using window restrictors during the day and always closed windows at night, mainly for fear of burglar and insects. Furthermore, all internal doors were kept closed, impeding cross-ventilation and as such greatly reducing the capacity to purge heat.

As for the flats, which were not surveyed using the questionnaires for budget limitations, a scarce reliance on natural ventilation (except for bedroom in A10, where nonetheless windows were left open with security restrictors) seemed not to affect thermal comfort as much as it did for the houses. This, combined with the information gathered during the interviews, confirming lower occupant densities and less time spent at home, suggested internal heat gains were the most impacting factor on overheating.

Ventilation via MVHR

While the primary function of an MVHR system is to provide fresh air, rather than purge heat (air extract/supply rates are not sufficient per se), the usage of MVHR in by-pass mode (i.e. excluding the heat exchange) was accounted for in the PHPP as a contribution to summer cooling. Furthermore, guides and user manuals distributed to residents seemed to be identifying mechanical ventilation as the main cooling strategy.

Following the summer study, an inspection was commissioned by the client, revealing how due to lack of maintenance and air filter replacement, the MVHR were providing insufficient low ventilation levels for block D and nearly no ventilation for the units in block C, requiring re-commissioning. This is believed to have exacerbated overheating, given the scarce reliance on window opening observed for some of the monitored households.

Conclusions

Overall, the monitored properties showed a poor thermal performance and a high occurrence of summer overheating, both above the PHPP predictions and the maximum allowed exceedance (10%) for the Passivhaus standard. However, this occurred with different degrees of severity and no factor alone was found to be responsible for it.

All properties were occupied by social housing tenants. The flats had smaller households and were not heavily occupied during the day. The houses, occupied by bigger families who stayed at home most of the time, showed more intense occupancy pattern and a more intense usage of appliances leading to high internal heat gains. This was true for all properties with the exception of D14, who showed the lowest occurrence of overheating.

Given the underperformance of the MVHR, cooling was entirely dependent on window opening. PHPP conservative assumptions only accounted for low air exchange rates through opening windows, and as such only the households who allowed abundant natural ventilation benefitted a lower occurrence of overheating compared to the PHPP predictions.

The PHPP, despite being a robust and extensively validated tool, may be inadequate to assess the full extent of the risk of overheating. While standardised assumptions are usually acceptable when seeking Passivhaus certification, a careful evaluation of critical factors such as occupancy patterns is crucial, if the PHPP overheating risk assessment is to be interpreted as an indication of present and future in-use performance.

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Climate-Responsive Façade Design for Office Buildings in London

Herman Calleja[1,2]

[1]ChapmanBDSP, London. herman.calleja@chapmanbdsp.com
[2] Architectural Association, London. herman.calleja@aaschool.ac.uk

Abstract: Cooling demand accounts for approximately 25-30% of the total regulated energy consumption of an office building in London. This is mainly a consequence of the high internal heat gains and large unprotected glazed façade areas. The cooling load is expected to increase further due to the city urban heat island (UHI) effect and climate change.
Through parametric analytical work, this research assesses the impact of overheating risk and design potential for free running offices in London, when considering CIBSE TM49 2050 weather data; thus, omitting the need to rely on mechanical cooling systems during the warm season. The results indicate the possibility to design out the need for cooling. The study also finds a strong relationship between overheating and the maximum average hourly internal heat gains, thus establishing a recommended early design stages threshold.
Subsequently two office projects where parametric environmental design has been used to inform the façade design are illustrated.

Keywords: parametric environmental design, overheating, office, facades

Introduction

Today's availability of algorithmic tools allows environmental performance data to inform the design process instantaneously. In such cases, targeting the right criteria or threshold is critical. The study has undertaken iterative dynamic thermal modelling to assess the potential of free running office buildings that comply with CIBSE Technical Manual (TM)52 when applying CIBSE TM49 2050 weather projections for London.

Iterative analytical work was carried out to assess simultaneously both thermal and visual comfort for a base case office. The assumptions and the inputs selected in the modelling reflect closely the mode of operation of a typical UK office. Based on the results of the analytical work executed, a recommended maximum threshold of internal heat gains was identified.

The application of internal and solar gains threshold and the potential of integrated parametric thermal modelling is illustrated through two projects that are currently being developed.

Aim of Study

Both in the academia and in professional environmental design consultancy, raises the request for a study to inform the façade shading strategy. The research explores which are the potential façade shading and glazing ratios strategies that would allow an office building in London urban area to achieve occupant visual and thermal comfort without relying on auxiliary cooling, achieving a free running environmental performance through parametric dynamic thermal modelling (DTM).

Methodology

Iterative simulations varying the glazing ratio from 20% to 100% and shading intensity, that is, shading element depth to spacing ratio (D/S), from no shading to 1.2D/S for an office space were carried out. Thermal and visual comfort has been assessed for these multiple simulations. The results were analysed to identify a common denominator that can be used as an initial indication of overheating risk in parametric environmental design. The studies were carried out on south and west-facing elevations which are the elevations that are mostly at risk of overheating. The study concludes by giving two applications of how façade design may be informed by this methodology.

Comfort Criteria

Thermal Comfort Criteria

Adaptive Comfort Model and Assessment

As shown by McCarthy and Nicol (2002) the temperature at which occupants feel at comfort is related to the running mean of daily average outdoor temperature. This is an additional refinement to an adaptive comfort criteria based on the monthly mean as proposed by DeDear and Brager (2002) and others. EN 15251 builds on the work of McCarthy and Nicol and today this comfort model equation is widely accepted and is also included as a design guide (CIBSE, 2015) for free running buildings as:

$$\theta_{comfort} = 0.33 * \theta_{rm} + 18.8^{o}C$$

Where θ_{rm} is to not exceed 30^{o}C and an additional ±3^{o}C comfort band may be applied for new office buildings that fall under Category II (Cat II: new buildings and renovations excluding spaces used by highly fragile occupants, such as sensitive hospital wards).

The overheating assessment was undertaken in line with CIBSE TM52 guide (CIBSE, 2013) which is based on the EN 15251 model. TM52 assesses three overheating criteria for the period of May to September for free running buildings. Any space that does not satisfy at least two of the three criteria is considered to have failed the assessment;

- Criterion 1: The operative temperature is not to exceed the upper comfort limit of the EN1521 comfort band by more than 1^{o}C for 3% of the occupied hours (i.e. 38 hours).
- Criterion 2: The summation of the number of hours exceeding the comfort band in a single day, multiplied by a respective factor of ΔT, is to be lower than 6.
- Criterion 3: The operative temperature is to be not more than 4^{o}C higher than the comfort band upper threshold.

Visual Comfort

In the UK the methodology most widely used in assessing daylight is the Daylight Factor. However, this is a metric that does not consider the influence of local geographic or climatic conditions. For a more accurate assessment Daylight Autonomy (DA), a climate-based daylight assessment method was selected. As recommended in various standards (CIBSE, 2015), an illuminance level of 300 lux – 500 lux is recommended for office spaces. What is still lacking agreement between authors is what is the correct upper threshold that defines over-illuminance or glare (Mardaljevic, 2015)? In this study a frequently accepted threshold of 10x the target illuminance (Reinhart, 2011), that is 5000 lux, was adopted. The Useful Daylight Illuminance and Annual Sunlight Exposure assessments were not considered as their thresholds, 2000 lux and 1000 lux respectively, are nowadays questioned (Mardaljevic, 2015).

Assumptions

Weather file

The selection of the weather data has a significant impact on an overheating assessment. The data used in this study is taken from CIBSE TM 49 (CIBSE, 2014 a) for London Weather Central station. The standard includes various weather data sources with projections for 2020, 2050 and 2080 based on UKCP09 climate projections considering the percentage of probability and global emissions scenarios. Considering the lifetime of a new building, this study was based on a 2050 projection considering medium (most likely) CO_2 emissions scenario. Although as shown in figure 1 the difference in emissions scenarios is quite low for 2050 projections. As highlighted by CIBSE (2014 b) the 50-percentile data is the most likely projection and hence this was adopted in the study to avoid under-designing (10-percentile data) or over-designing (90-percentile data).

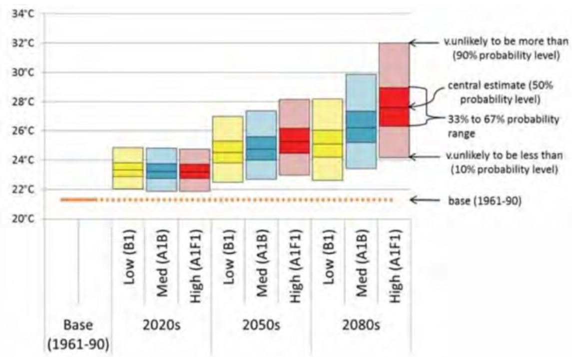

Figure 1 Summer mean daily maximum temperature for different emissions scenarios

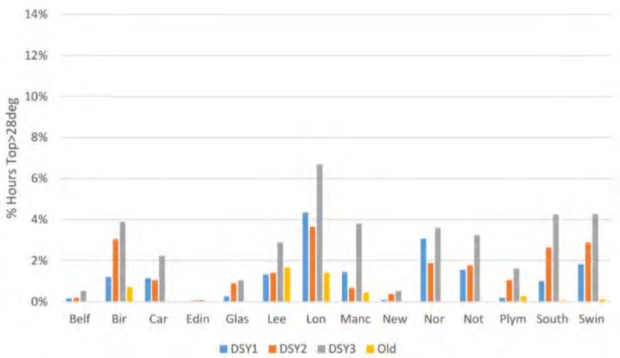

Figure 2 Percentage of occupied hours above 28^{o}C for an office using different current climate weather files

Finally, Design Summer Year (DSY) 3, a summer with a prolonged period of sustained warmth based on 1976 data (GLA, 2015) was selected, since as indicated in figure 2 this always results in the highest overheating risk for offices (Virk and Eames, 2016).

Internal conditions

National Calculation Method (NCM Activities 5.2.7) internal conditions, including small power loads, occupancy density and schedules, were applied to the office space thermal model, as these conditions are what is typically found in offices in England (DCLG, 2014). Daylighting control was applied to the artificial lighting to reduce unnecessary lighting gains.

Design Research

Tools

DTM was undertaken using EnergyPlus in Honeybee (Roudsari, 2013) through the Grasshopper platform within Rhinoceros NURBS modelling suite. Further analysis on load breakdown on Cases 1, 2 and 3 (identified in Fig. 5) were carried out through EDSL TAS. Daylighting studies has been conducted via DAYSIM using Honeybee plugins.

Test case parameters

For the purpose of this research a south-facing office with W x D x H dimensions of 10m x 6m x 3m has been assessed. The 6m depth was selected as this would be the area that is mostly influenced by the façade performance (Baker and Steemers, 2000; DCLG, 2014).

The building fabric properties are illustrated in table 1. The U-values applied are standard but not best practice performance (to allow for a wider applicability of the study), close to the building regulations Part L2A notional parameters. Since the aim is to achieve a free running office space, a low g-value (0.3) that however allows a good light transmittance (60%) was selected. For the daylight simulation, a more conservative 60% light transmittance has been used as a 70/30 glazing specification may be considered very onerous.

Table 1 Building fabric properties

	U-Value	G-Value	Frame factor	Light transmittance
	W/m².K	N/A	%	%
Opaque Wall	0.21	N/A	N/A	N/A
Window	1.70	0.30	0.15	60%

The weather data indicates an average diurnal temperature range of 9^{o}C throughout the period of overheating risk (May-September), a good indication for the application of thermal mass with night time ventilation as a cooling strategy (Santamouris, 2007). Thermal mass may offset 60% of the cooling load of a conventional office (Allard, 1998). As shown in figures 3 and 4 this strategy may reduce the resultant temperature by over 5^{o}C. In the study carried out, 50% of the internal walls area and the ceiling have high thermal mass. Furthermore, the percentage of openable façade area was kept as 25% throughout all the simulations. Each opening having a discharge coefficient of 0.61.

The iterative study was conducted on horizontal shading devices as this is the most effective strategy for this orientation as may be illustrated through shading masks. Studies were also carried out on a similar west-facing office, with vertical fins, to assess the facades with the highest overheating risk.

Results Analysis

The results indicate that it is possible to design offices that satisfy TM52 overheating criteria using TM49 2050 weather data without relying on auxiliary cooling. All the TM52 criteria were tested, however, figure 5 shows only a single criterion as it was the most decisive criterion. As indicated in figure 5, TM52 may be met by varying glazing ratios, up to not higher than 65% and varying shading density. However, if a relatively high glazing ratio, >60%, is selected the demanding shading density required results in poorly daylit spaces. As shown in figures 5 and 7 glazing ratios between 40% and 60% can provide a good level of daylighting and meet the thermal comfort requirements, when the correct shading density, illustrated on figure 5, is selected. The glazing area may be increased if a lower g-value glass is selected.

External temperature exceeds the comfort band upper limit for 131 hours, 10% of the occupied hours, which as shown in figure 9, coincides with the spikes of the office resultant temperatures. This indicates that daytime natural ventilation will not be an adequate cooling strategy during hot summer days, when the highest overheating risk occurs.

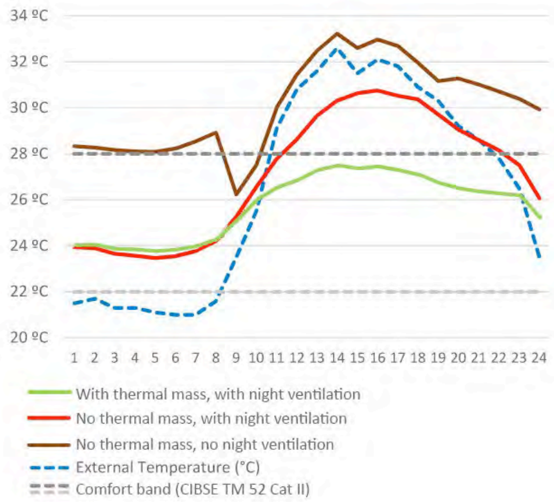

Figure 3 Summer day night time ventilation cooling

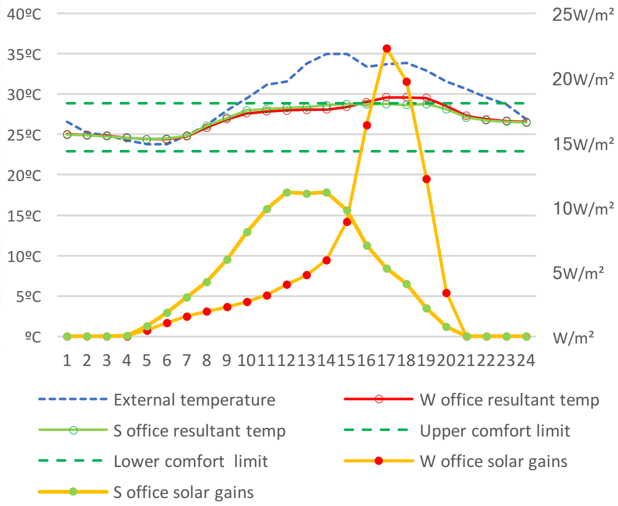

Figure 4 Summer day thermal mass effectiveness

Three simulations that are at the limit of satisfying the TM52 criteria (indicated on figure 5) were selected for further analysis; [1] 30% glazing with 0% D/S (unshaded), [2] 40% glazing with 20% D/S and [3] 60% glazing with 0.8 depth to spacing (D/S) ratio. As shown in figure 10, a common denominator of the three cases is that the average hourly internal heat gains, that is; occupant, equipment, lighting and solar gains. For the occupied hours (8:00 – 19:00), between May and September, this value is 28 – 29W/m² for the three cases. Simulations that failed to meet the overheating criteria (shown above the TM52 line in figure 5) have a higher value of internal gains. A similar study conducted on the West façade resulted in a threshold of 28W/m². This is close to a previous recommendation (OPDM, 2006) of 35W/m², however this study recommends a more challenging threshold of 28W/m². Nonetheless, this applies only for offices that benefit from night time ventilation and adequate thermal mass. It is interesting to note that excessive shading can result in a heat gains increment due to the use of artificial lighting (figure 10).

The analysis indicates that for a south-facing office, the average daily cumulative internal solar gains should not exceed 90Wh/m² (May to September). However, for a west-facing office, the internal solar gains for the same period need to be less than 75Wh/m². The solar gains threshold is lower for the west facade, since overheating risk on the west façade occurs during the late afternoon, from 3pm onwards. By this time of the day, the benefit of the night-time cooling is dissipated and the building has gained heat throughout the morning hours due to high external temperatures and gains from diffused solar radiation.

Furthermore, as indicated in figure 4, the solar radiation received by an office surges up very rapidly in a space of one or two hours from 4pm onwards due to the low sun position. Between May and September, the azimuth angle varies from 230^{0} to 260^{0} and the sun angle of elevation varies from 22^{0} to 36^{0}, being nearly perpendicular to the west elevation. Results indicate that the peak hourly solar gain should be limited to not exceed 25W/m² for 90% of the occupied time. These values are only indicative and are meant to guide the design in the early stages. Nonetheless, further investigation, considering different shading strategies and project specifics, may have to be undertaken to assess this parameter further.

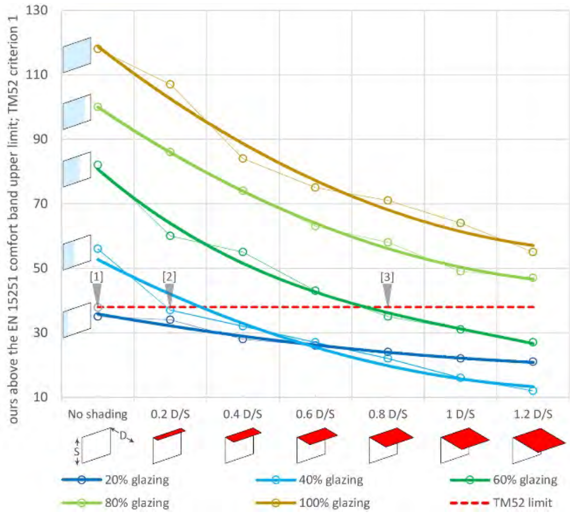

Figure 5 Overheating hours. Comfort limit: 38 hours

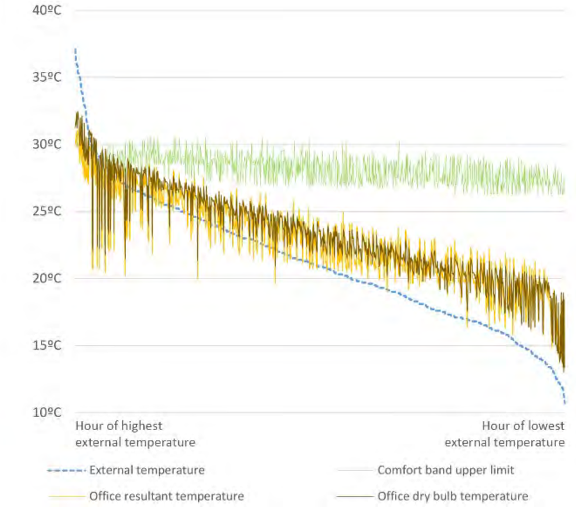

Figure 6 Case [3] days meeting TM52 comfort criteria

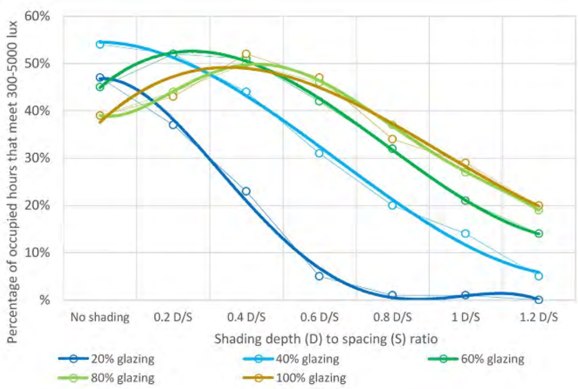

Figure 7 Daylight Autonomy [300 – 5000 lux]

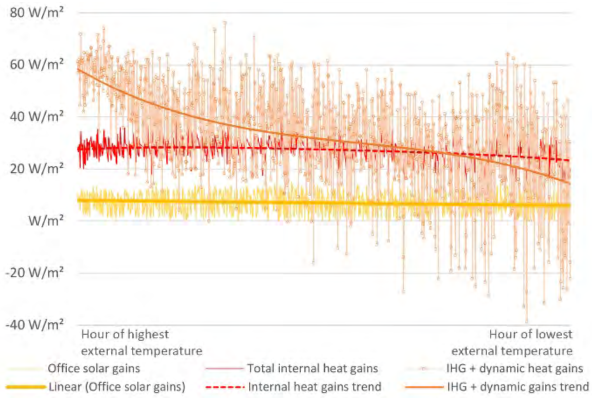

Figure 8 Case [3] heat gains of days satisfying TM52 Cr. 1

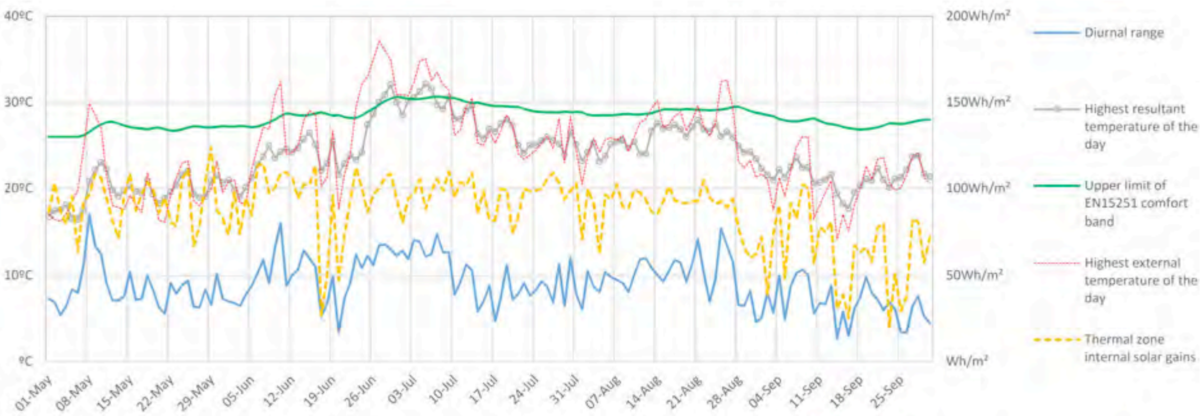

Figure 9. Case [3] – Correlation between external temperature, solar gains and overheating risk

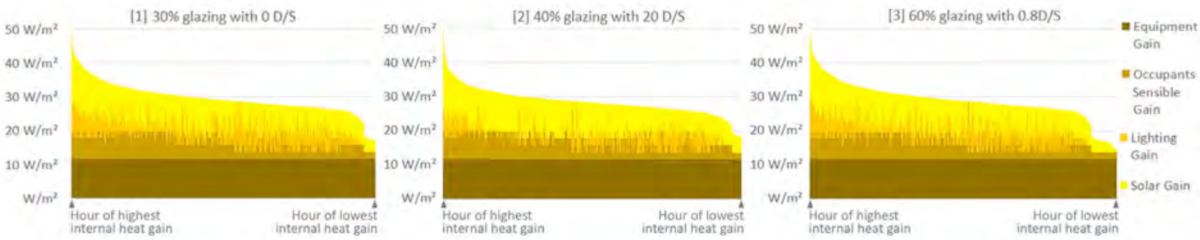

Figure 10 Internal heat gains for all the occupied hours (May – September) for simulations [1], [2] and [3]

Application of parametric dynamic thermal modelling

The availability of algorithmic tools allows performance data to inform a dynamic design process (Friesen, 2009), allowing the design to meet a 'dynamic equilibrium between aesthetics and optimization' (Burry, 2010). However, for the stochastic parametric design process to be meaningful, the right parameters need to be set. Hence extracting the correct threshold figure/s that can indicate compliance with the comfort criteria is an important initial step prior to undertaking parametric DTM. Two projects, conducted at ChapmanBDSP, where parametric environmental design contributed to the façade design are illustrated below.

This approach has been adopted during the façade design exploration process for a mixed-mode office in London. For the given orientation (figure 12), and programme, 165kW/m^2 in incident solar radiation for the occupied period between May and September indicated the most effective shading strategy, when comparing extent of shading surface area to the reduction in incident solar radiation. Subsequently different façade articulations (Fig 11) that allow the same amount of solar gains were explored together with the architect.

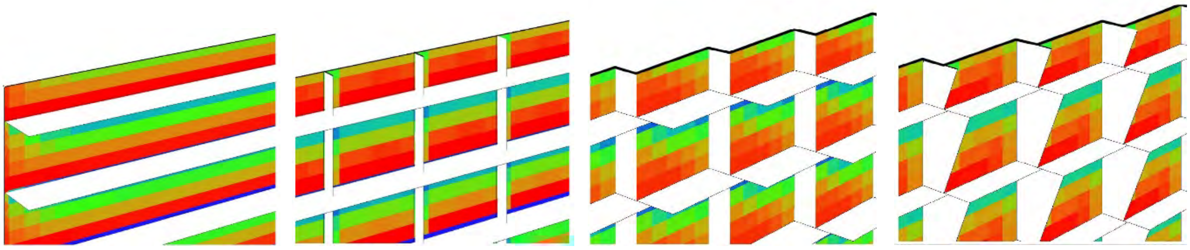

Figure 11 Façades articulations that allow similar amount of solar gains for a southwest orientated office

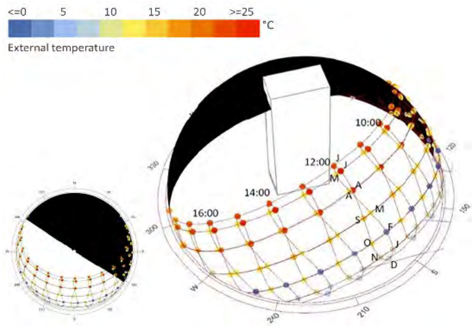

Figure 12 Office space shading mask analysis

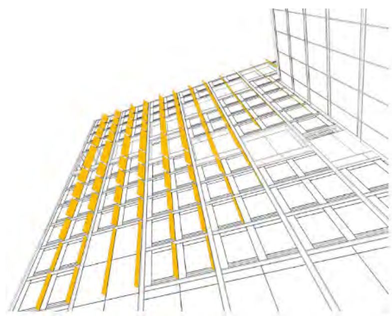

Figure 13 optimised vertical shading fins

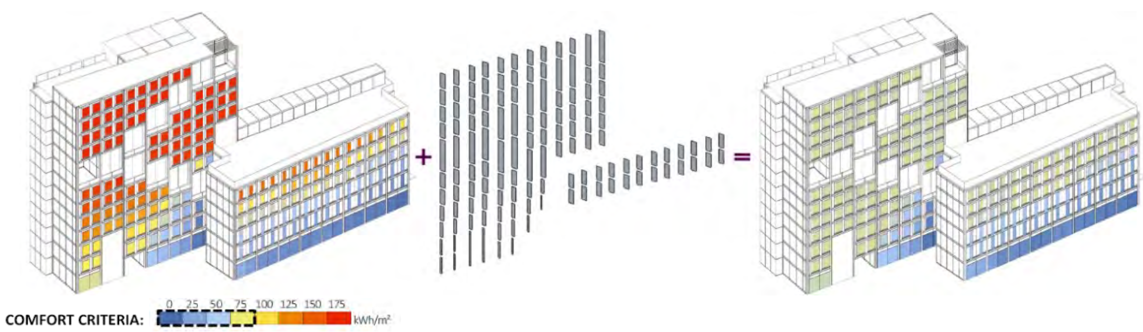

Figure 14 Façade shading optimisation for a naturally ventilated office building in London. Architect: RSH+P

In another office project, that is being designed to be naturally ventilated (architect: RSH+P), the maximum allowable incident solar radiation for an exposed cellular office was identified. Subsequently an algorithm was applied such that the incident solar radiation for an individual office does not exceed this value, thus avoiding over-designing the lower vertical fins since the lower part of the building was significantly overshadowed (figures 13 and 14).

Conclusion

The studies undertaken through dynamic thermal modelling show that with a well-designed façade, integrated with an adequate mode of operation, it is possible to achieve cooling-free offices in London, that comply with CIBSE TM52 for 2050 weather data when considering a medium (the most likely) global CO_2 emissions scenario.

Based on the analytical work carried out, an early design stage maximum average hourly internal heat gains threshold of $28W/m^2$ is recommended for naturally ventilated offices in London to future proof the building for 2050, based on TM49 weather data projections. As indicated through two case studies, this threshold may be used to inform parametric thermal dynamic modelling while exploring different generative morphologies.

Recommended further studies include considering varying orientations and urban contexts, different shading geometries, carrying out sensitivity studies on the adequate occupancy schedules and occupancy gains considering a variety of office spaces including areas for hot-desking, meeting rooms and study areas.

Acknowledgements

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Design to Thrive

Predicting Evaporative Cooling Performance of Wetted Decorative Porous Ceramic Systems in Early Design Stages

John Chilton[1], Mark Guillott[1] and Juan Vallejo[2]

[1] Department of Architecture & Built Environment, Faculty of Engineering, University of Nottingham, UK. John.Chilton1@nottingham.ac.uk;
[2] Department of Architecture & Built Environment, Faculty of Engineering, University of Nottingham, UK. Mark.Gillott@nottingham.ac.uk;
[3] Department of Architecture & Built Environment, Faculty of Engineering, University of Nottingham, UK. Juan.Vallejo@nottingham.ac.uk.

Abstract: Passive evaporative cooling methods using porous ceramics were widely applied in the Islamic culture to reduce ambient air and surface temperatures and thus improve thermal comfort conditions under hot-dry environments. However, the integration and performance prediction of evaporative Porous Ceramic Cooling (PCC) systems in contemporary architecture is still complex due to the large number of environmental and physical parameters involved. This paper explores alternative and more efficient applications of PCC systems: maximising cooling capacity, minimising water consumption and promoting the artistic expression of ceramics in architecture. Laboratory testing and fieldwork were conducted using an optimised prototype and monitored data provided with relevant information regarding cooling performance. The obtained data was used to calibrate a Computational Fluid Dynamic (CFD) model which was used to explore the performance of different ceramic designs exposed to a wide range of environmental conditions. The results were post-processed to develop a multi-steady state calculation tool to advise professionals on the design and performance prediction of PCC systems at early design stages. The system proved to be a good alternative to minimise local thermal discomfort, reducing ambient air temperature by 2°C and mean radiant temperature by 1.8°C on the leeward of certain PCC systems.

Keywords: evaporation, ceramic, cooling, performance prediction.

Introduction

The last decade has witnessed how passive cooling techniques have become increasingly attractive methods to architects for delivering healthy and comfortable environments as an alternative to the 'default' use of mechanical cooling systems. The significant benefits of natural ventilation over mechanical systems are now widely appreciated, highlighting the mitigation of sick building syndrome and the increase in occupants' productivity. The application of evaporative cooling methods in contemporary architecture is, however, less frequent, and is normally executed using misting systems or porous media (Ford et al., 2012). The applicability of these systems is also limited to hot and dry climates: high temperatures and low water vapour content on the air to allow more water liquid particles to evaporate. Recommended ambient wet bulb temperatures for a successful application of these systems range from 22-24°C (Santamouris et al., 1996). Although passive evaporative cooling methods have been successfully applied in architecture, the early integration of these systems in the design is often not considered, and usually delegated to specialists at later stages. This practice increases the risk of underperforming systems and not meeting the initial project requirements.

The benefits of addressing the integration of passive strategies from early stages are thus evident: delivery of a better space layout coupled with the system, improved efficiency and avoid of under/over-performing predictions. Simple steady-state and manual calculations are traditionally used in most fields to fulfil this task, and proved to be reliable and quick to use, providing confidence in the performance of the system. The physics involved in natural ventilation for convective cooling are manageable with manual calculations, and steady-stage tools have recently emerged to assist architects and engineers in the design of natural ventilation strategies. Optivent 2.0 (Aparicio, 2015) is in line with widely used design guidelines (ASHRAE, 2005 and CIBSE, 2016) and has been applied and validated in a large number of projects worldwide, providing a good basis for later stage more detailed analysis.

Coupling a natural ventilation strategy with an evaporative cooling method will improve the cooling capacity of the whole system, but the physics involved during the evaporation process are substantially more complex as more parameters are involved (porous surface area, system geometry, ambient vapour pressure, air velocity, etc.), making the performance prediction computationally intensive and not manageable with manual calculations. With limited time on early design stages to perform advanced simulations, designers usually lack confidence in the performance of the proposed cooling strategy, which often leads to banal assumptions on the cooling capacity of water bodies placed in the design.

This paper describes the development and the features of a multi-steady-state calculation tool to predict the cooling performance of wetted decorative porous ceramic systems in early stages of the design process. The tool is an outcome of a research which involved the design and manufacture of an optimised ceramic prototype, the monitoring of its cooling capacity through laboratory testing and fieldwork, and the execution of a parametric analytic work through the definition of an advanced CFD model. The tool is oriented to architects/designers and aims to promote the efficient use of alternative evaporative cooling methods, enhancing at the same time the artistic expression of ceramic elements.

The Wetted Porous Ceramic System

The use of ceramic in architecture is well spread in Europe and its application extends to walls, flooring, double skin façades or latticework. In Spain and Italy, for instance, the industry of ceramic is well stablished and expanding, and international Ceramic Exhibitions attract every year more than 80.000 professionals worldwide (Cevisama, 2017). Recent advances in material science, emerging technologies and production methods (Bechthold et al., 2015) bring architects the opportunity to rethink the application of ceramic in architecture and further develop other attributes, including evaporation over the porous surface.

This research involved the design and manufacture of an optimised extruded porous ceramic prototype that maximises cooling capacity and minimises water consumption. Among the main objectives of the design process were the increase of the ceramic surface to volume ratio, minimise airflow resistance and the supply of water directly to the ceramic surface. The prototype was manufactured by the Spanish company Ceramica Decorativa SA and was used to undertake experimental work and explore the potential of ceramic elements to induce evaporation. The system consists on tubular-shaped samples arranged over a vertical plane. Water is supplied from the top using a drip irrigation system, and engraved water channels distribute the fluid along the vertical direction, allowing a uniform water distribution over the ceramic surface. When the wetted surface is exposed to an airstream, water molecules separate from a liquid structure to the air, absorbing heat from the surrounding air (Figure 1). As result, an air temperature reduction and humidity increase is achieved in the leeward of the ceramic system. The heat content of the air and its capacity to hold vapour can be indicated by its dry bulb to wet bulb temperature depression (DBT-WBT).

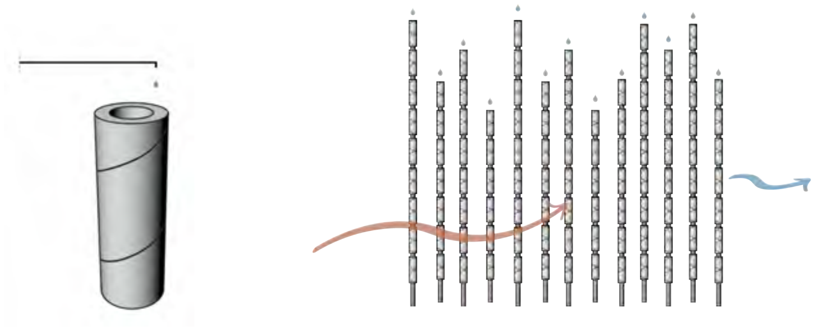

Figure 1. Extruded porous ceramic prototype and system concept.

Application

The system allows a wide range of applications, but its integration in architecture must be coupled with a ventilation strategy that drives air through the ceramic surface. Air can be driven passively by buoyancy forces, and excessive warm airflow rates should be avoided. The connection of two adjacent spaces presenting different air temperatures will drive the cool air to the warmer space, making the boundary between both spaces a desired location to place the PCC system. To maximise efficiency, the space layout and area of influence should also be carefully designed: excess of heat gains, exposure to direct solar radiation and poor user accessibility can lead to poor performance. These recommendations make the system suitable for semi-outdoor spaces, and ideally applicable to transitional spaces. Some application examples of PCC systems in architecture are reception spaces in atria, facades, or circulation areas around a central courtyard (Figure 2).

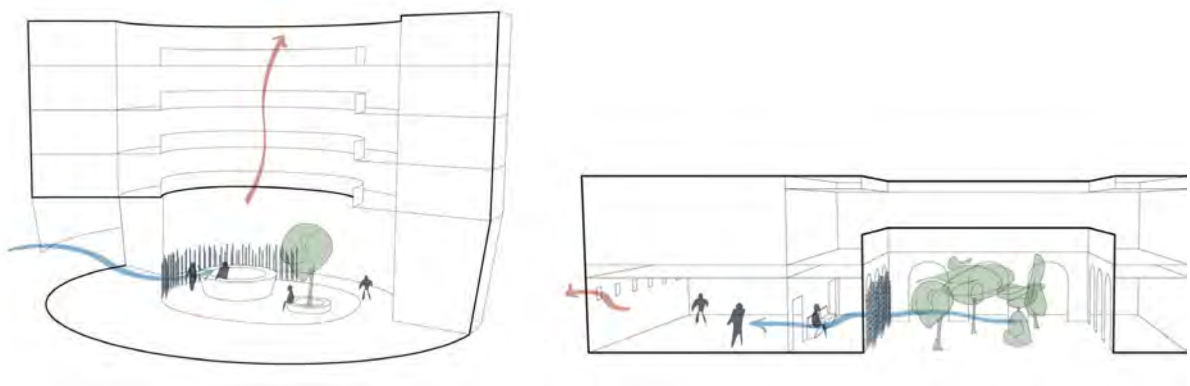

Figure 2. Application examples of PCC systems in architecture.

Experimental Studies

The conducted experimental studies aimed to monitor and evaluate the cooling capacity of the manufactured prototype when exposed to a wide range of ambient air temperatures, humidities and air velocities. The studies were first conducted under controlled environmental conditions (laboratory testing) using an environmental chamber; and second, in a semi-outdoor space (fieldwork) under the hot and dry conditions during the month of August in Granada, Southern Spain (Latitude: 37° 10').

Laboratory Testing

The laboratory studies explored the temperature reduction achieved and water consumption of different ceramic arrangements (and thus exposed ceramic surface areas) within a cross section of 500x500 mm^2 under wide range of environmental conditions. With the aim of improving the design and efficiency of the system, three arrangements presenting blockage ratios (opaque to free cross section area) of 25%,40% and 50% were tested (Figure 3).

The samples were placed in the centre of an 1800x500x500 mm insulated box, with an air intake and exhaust at the front and the back respectively. Temperature and humidity on the windward and leeward of the ceramic surfaces were constantly measured with nine Resistance Temperature Detectors (RTDs) and two Humidity probes in line with the Standard Test Method D3464-96 (ASTM,2014). The samples were initially saturated, and at the end of a fifteen minutes' analysis cycle they were weighted again to determine the evaporation rate and water consumption.

Figure 3. Laboratory work set-up and ceramic arrangements.

The collected data revealed the air temperature reduction achieved on the leeward of the ceramic system is directly proportional to the DBT-WBT (Figure 5). This confirms that warmer and dryer conditions yields to bigger temperature reductions, increasing its effectiveness. Moreover, the cooling achieved responded to the shape and number of ceramic elements: best results were obtained with ceramic arrangements presenting higher blockage ratios (50%), which confirmed the importance of maximising exposed porous surface area without compromising the airflow path. The results also suggest that a 2 degrees' temperature reduction is achievable with DBT-WBTs above 14°C (i.e. DBT:34°C & RH:25%).

Fieldwork

The experimental mock-up conducted in Granada aimed to evaluate the dynamic behaviour of a PCC System exposed to daily variations in environmental conditions. Measured air temperature during the operational period ranged from 24°C to 34°C, relative humidity ranged from 30% to 50% and air velocity ranged from 0m/s to 0.6m/s. A 2000x2200mm ceramic system presenting a 25% blockage ratio was built and placed on a transitional space, naturally ventilated, shaded and wind sheltered. Temperature and humidity on the windward and leeward of the ceramic surface were monitored using temperature and humidity sensors at 400mm, 2000mm and 5000mm distance from the ceramic walls (Figure 4).

Figure 4. Fieldwork PCC system mock-up.

The collected data confirmed an expected wider amplitude of ±0.3°C in the temperature reduction achieved, which mainly responded to air velocity variations. Moreover, these temperatures followed the same linear profile found in the conducted laboratory analysis, presenting higher temperature reductions with hotter and dryer conditions (Figure 5).

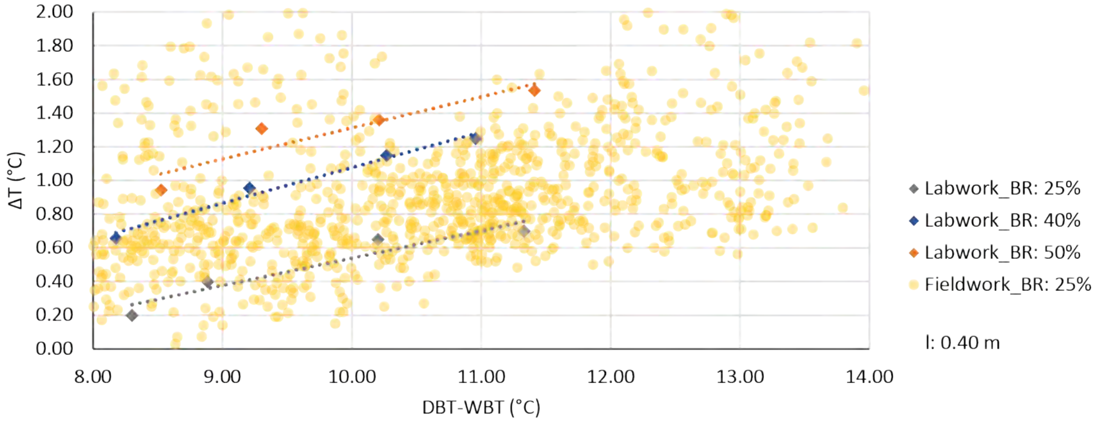

Figure 5. Laboratory & Fieldwork data- monitored temperature reduction achieved.

Computational work

A valid numerical model using the commercial CFD software Ansys Fluent® was defined to simulate the physics of evaporation on wetted ceramic surfaces. The model is a transient simulation with water phase change taking place on the ceramic surface, and consequently mass transfer from liquid to vapour in a rectangular prism (1000x1000x2000mm) fluid domain. An extensive parametric study using this numerical model was conducted to generate a database of PCC performance to be compiled in a design tool described below.

The parametric study consists of sixteen environmental conditions: four DBT-WBT (8,10,12, and 14°C) under four air velocities (0.25, 0.50, 0.75 and 1 m/s). Four ceramic shapes presenting different flow resistance (drag coefficient: 0.56, 1.10, 1.24, and 1.37) were analysed for four different arrangements (blockage ratio: 25,30,40 and 50%). Overall, the study involved 256 simulations.

Porous Ceramic Cooling System Design Tool

The tool is a multi-steady-state model designed to assist designers in the sizing and performance prediction of a PCC system in early design stages with minimum user inputs and time consumption. It also aims to raise awareness and knowledge on the benefits and limitations of this system. It estimates temperature reduction, humidity increase and water consumption of a PCC system exposed to any environmental conditions and for any ceramic shape and arrangement within the range of values analysed in the computational work.

User Interface & Methodology

The tool is structured in three main bodies: Microclimatic Data, Ceramic System Data and Evaporative Cooling Performance. The first two contain the user inputs to define the environmental conditions and the dimensions of the ceramic system. The last body outputs the cooling performance of the defined system.

Microclimatic Data

A 24-hour daily profile is generated from the definition of a maximum and minimum air temperature (Huld, 2006). Humidity is given as absolute value (g/kg), and air velocity in m/s, assuming both parameters constant for the daily period. Steady-steady tools like Optivent2.0 may assist in the definition of air velocity as result of a buoyancy driven natural ventilation strategy. Finally, a schedule to define the operation time will be consider to estimate the total water consumption of the system for the given day.

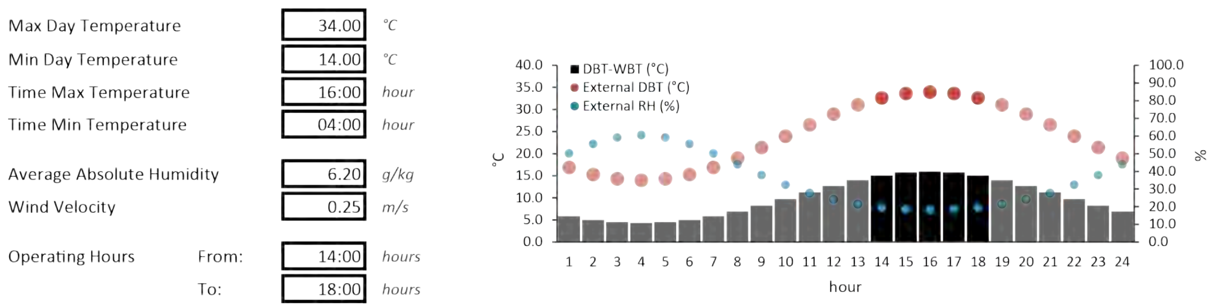

Figure 6. PCC tool – Microclimatic data input.

Ceramic System Data

The system is defined by providing the geometrical shape of the ceramic sample, which is associated to a specific drag coefficient; the total system (inlet) area, given by the corresponding width and height; and the number of columns arranged over the vertical plane. The tool then associates a blockage ratio to the upcoming interpolation process. Finally, a distance from the wetted surface can be set in order to obtain the results for the given point.

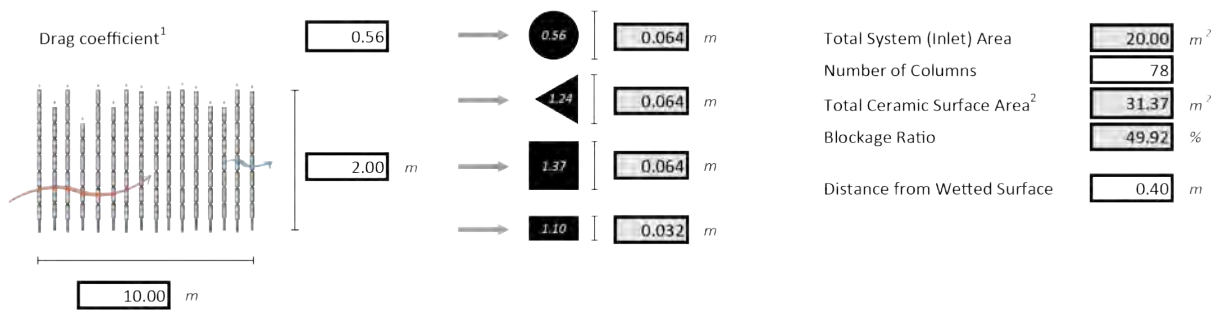

Figure 7. PCC tool – Ceramic System data input.

Evaporative Cooling Performance

The collected inputs (DBT-WBT, air velocity, drag coefficient and blockage ratio) are used to access the parametric database and perform a series of interpolations between the nearest values in a logical order to obtain the final output. These results include the mean cooling achieved, as well as the average sensible to latent ratio over the operational period. The calculation of sensible and latent cooling is in line with ASHRAE (2005), and they are proportional to the air density, specific heat or latent heat of vaporization, the airflow rate and the average temperature reduction or humidity increase achieved. Water consumption calculation derives from the latent cooling and is equivalent to the total amount of water evaporated per unit of time. Finally, a predicted air temperature, mean radiant temperature reduction and absolute humidity increase is plotted for each operation hour and for the defined distance from the ceramic wall.

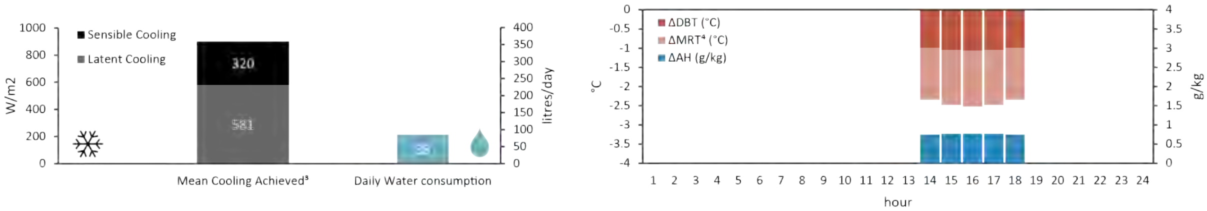

Figure 8. PCC tool – Evaporative Cooling Performance output.

Data Validation

The tool outcomes were validated using laboratory data. The tubular shaped samples presenting blockage ratios of 25,40, and 50% were used for the validation, and the predicted temperatures at 0.40m distance from the ceramic wall for a wide range of environmental conditions were compared against the monitored data. Following the same methodology, the water consumption for each hour of operation was also compared (Figure 9).

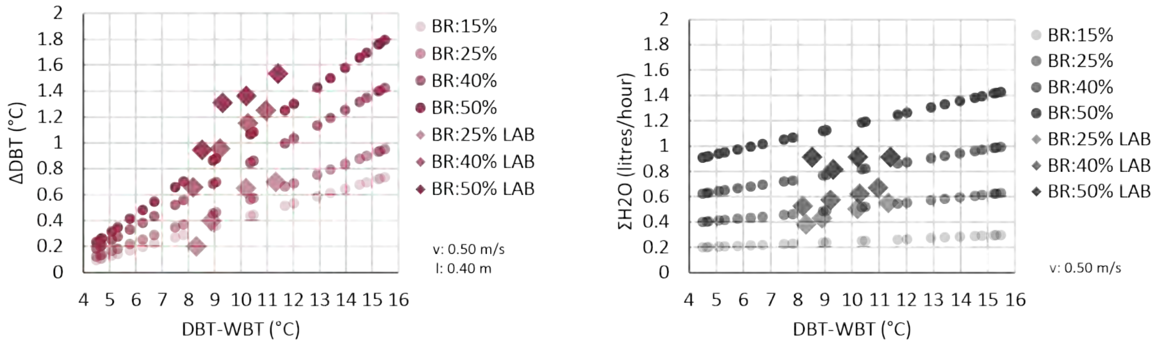

Figure 9. PCC Tool & Laboratory data – Predicted vs monitored temperature reduction and water consumption per square metre of ceramic system.

The above graphs confirmed the predicted temperature reduction and water consumption given by the tool are in line with the laboratory data, both presenting a linear relation with DBT-WBT for a constant air velocity of 0.50 m/s.

Discussion and Conclusions

This research explored the potential of alternative conductive and evaporative cooling techniques using decorative porous ceramic systems to reduce ambient air temperature. Monitored data confirmed the linear relation the between environmental conditions and the cooling capacity of a PCC system, and theoretical models allowed to explore the benefits of certain ceramic shapes and arrangements. Higher ceramic surface areas and aerodynamic shapes enhance evaporation, and the ceramic arrangement on the vertical plane must avoid wind-sheltered areas. Moreover, the temperature reduction and humidity increase achieved on the leeward of the ceramic surface reduces with distance from the ceramic wall, and confirms the small area of influence of the system, which in some cases remains below two meters long. The space layout and the human relation with the PCC system must be certainly considered on early design stages.

The multi-steady-state tool presented in this paper allows to predict cooling capacity and water consumption of a PCC system with a reduced number of inputs and accepting a wide range of ceramic shapes and arrangements. By using the tool, designers could predict, for instance, that a 30 m^3 PCC system built with tubular ceramic samples arranged in the vertical plane and presenting a blockage ratio of 50%, can reduce the surrounding air temperature by 2 degrees in the peak hours of the day (DBT-WBT≥14°C). The water consumption for one hour of operation is estimated 72 litres, half the average household water consumption in Europe. The mean radiant temperature (MRT) also makes a considerable impact on the human perception of the environment. Monitored surface temperatures (ST) during the experimental work responded to the expression ST= DBT-0.8(DBT-WBT) + 3 (°C), and MRT at any distance from the ceramic system can be estimated from the calculation method initially defined by Fanger et al. (1985) and adopted by ISO 7726 (1998) and ASHRAE (2005). Continuing with our example above, the MRT depression achieved downstream the ceramic surface is 1.8°C at 1m distance, and 0.5°C beyond 3m. By coupling the air temperature reduction, the achieved mean radiant temperature and the psychological cooling effect of air movement, the user perception of the environment is considerably improved, making the convective and evaporative PCC system a good alternative to minimise local thermal discomfort during hot and dry seasons.

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Overheating and health risks in refugee shelters: assessment and relative importance of design parameters

Daniel Fosas[1*], Dima Albadra[1], Sukumar Natarajan[1] and David Coley[1]

[1] Dept. Architecture and Civil Engineering, University of Bath, Bath, UK
[*] Contact: d.fosas@bath.edu

Abstract: There are now more than four million refugees living in camps around the world. The majority of such camps are within inhospitable environments, often with extreme climates. This paper focuses on the thermal conditions of shelters in the Azraq refugee camp (Jordan), subject to an arid climate with high temperatures during the hot season. Due to political and other sensitivities, whole-, or multi-year monitoring of occupied shelters—and hence the empirical determination of overheating—is difficult. Instead, internal conditions in the shelters were monitored for three weeks in summer and used to validate computer models of the accommodation. These models were then used to generate annual predictions of overheating assessed through overheating criteria based on thermal discomfort and physiological indicators of heat stress. Building on these results, the performance of alternative designs specifications or shelter operation strategies were investigated through parametric analysis. The results show maximum indoor temperatures over 45°C. Overheating thresholds were exceeded for more than 20% of the year and physiological indicators suggest the possibility of health-threatening conditions. The use of alternative designs and strategies reduced overheating to nearly 2% of the year, with a steep reduction of severe heat stress indicators.

Keywords: refugees, shelters, overheating, health risk, thermal comfort

Introduction

The current number of forcibly displaced population in the world is among the highest on records of which a third, 20 million, are refugees (UNHCR 2017). The refugees from the Syrian Arab Republic alone represent 23% of the total refugee population with 4.9 million people. As part of the response to this crisis, they are often hosted in camps in neighbouring countries such as Turkey, Lebanon and Jordan. Given the location of camps and the severe conditions experienced in Jordan's climate, this paper investigates overheating discomfort and potential heat stress risk of refugees in these circumstances.

The thermal performance of shelters, and the indoor conditions they deliver, is a subject with a limited number of studies. One of the key concerns is the actual provision of a shelter as a humanitarian response. This constitutes a challenging task of paramount importance as it needs to deliver rapidly a scalable housing solution to an unexpected crisis of unknown duration. Among the few studies that focused on the thermal performance of shelters, there has been a greater number of studies dealing with cold environments (e.g. Crawford et al. (2005)) than hot ones (e.g. Cornaro et al. (2015)). This results in an underdeveloped area of research considering the number of people involved and the potential risks associated, especially for vulnerable occupants as children, one of the major refugee groups worldwide.

Consequently, this study evaluates the overheating risk in the Azraq refugee camp in Jordan (31.90°N, 36.57°E). Firstly, the application of different overheating metrics for discomfort and heat stress in the built environment is explored. Then, previous metrics are applied in the Azraq context to evaluate whether refugees are exposed to excessively hot indoor conditions regarding discomfort and heat stress. Lastly, the potential of passive strategies to reduce excursions from neutrality conditions to inform potential design improvements to current shelters is quantified. To accomplish these goals, the following hypotheses are established:

1. Refugees in considered shelters are exposed to indoor conditions outside the acceptable range established in the ASHRAE Std. 55 (2016).
2. Refugees in considered shelters are exposed to indoor conditions outside the recommended ranges for heat stress in the Pierce 2-node and Predicted Heat Stress (PHS) physiological models.
3. Current shelters cannot be optimized to avoid overheating discomfort through the passive measures considered.
4. Current shelters can be optimized to avoid severe heat stress through the passive measures considered.

Methodology

The study focuses on the Azraq refugee camp because of its exposure to the 'hot desert climate' (Köppen-Geiger zone BWh) and because it is based on a well-defined shelter design (figs. 1 and 2). As of April 2017, the camp hosts 53,914 refugees, of whom 57% are under 18 years old. Due to security concerns —among other considerations—, the structure of the camp and the arrangement of shelters cannot be modified. Owing to these considerations, the study was conducted in two phases. The first is a three-week field study, during which surveys and spot measurements of environmental conditions were collected. The second extrapolates annual overheating conditions via building and human thermal simulations.

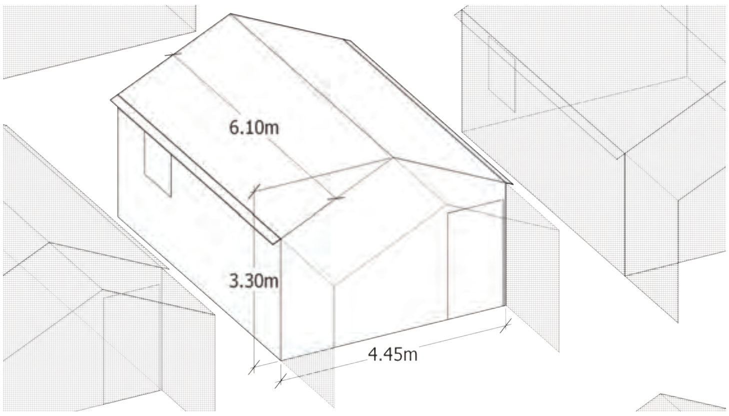

Figure 1. Description of the T-Shelter in Azraq refugee camp.

Figure 2. Example of shelter interior.

Field study

The field study was carried out from 31st August to 23rd September 2016. Here, randomly selected families completed a thermal and a social survey (n=36). The thermal survey included ASHRAE Std. 55 (2016) guidelines whereas the social one focused on factors such as perceived security, privacy or adaptation opportunities. Shelter units were documented 'as built' to track any discrepancies between the original specification and their actual conditions (e.g. shading devices, openings, insulation location, actual occupation…).

Simulation

The data collected during the field study was used to calibrate and validate the base shelter simulation. The model is based on the design specification (UNHCR 2016), were the findings of the social survey and shelter inspections completed missing information (e.g. occupancy pattern) or overrode contradictory ones (e.g. as built thermal insulation condition).

The spot measurements of different shelters were combined into a single time series and split into two groups, one to calibrate the model and another one to validate it. Uncertainties regarding model inputs were constrained to the following variables: infiltration (unknown; bounds estimated following construction details), ventilation effectiveness (unknown; e.g. surroundings influence on wind speed or discharge coefficients), occupation (variable between shelters) and U-value (bounded range of conductivity and thickness). A set of 72 simulations were used to calibrate these parameters and then validated with the remaining monitored data (fig. 3, EnergyPlus 8.6). The goodness of fit was evaluated through the peak and mean dissimilarity and the root mean square indicators (2.38, 0.36 and 1.47K, respectively). Given the between-shelter variability and the uncertainties in parameters such as ventilation and infiltration, these results were regarded as adequate for the purposes of this study.

Table 1. Parameters and cases to explore for the shelter design improvements (weather file: Guriat).

Parameter	Cases	Comment
Orientation [-]	[N, E, W, S]	One per cardinal direction.
Insulation [cm]	[1, 5, 10, 15]	Conductivity: 0.04 [$W{\cdot}m^{-2}{\cdot}K^{-1}$].
Thermal mass [-]	[light, heavy]	Light: current shelter composition. Heavy: 215mm perforated brick and plaster.
Thermal mass location [-]	[internal, external]	Relative position to the indoor space.
Occupancy [p]	[6, 12]	Original shelter design aims for 6p and surveyed occupation frequently reached 12p.
Shading [-]	[none, full]	None: current solar exposure (see fig. 1). Full: completely block solar radiation.
Ventilation strategy [-]	[daytime, always]	Daytime: as needed during 07-23h. Always: as needed (constant occupation).
Infiltration [-]	[original, reduced]	Original: current shelter estimated infiltration. Reduced: 25% of the previous value.
Opening effectiveness [%]	[10, 40, 70]	Multiplicative factor for opening areas. 10% is the fitted value in the calibration and 70% a value around illustrative reference levels (ASHRAE 2013).
Total	**3,072 models**	Every parameter-case combination.

The validated model was then used to extrapolate annual overheating performance. Given the limitations to monitor typical external conditions throughout the year in this location, the weather files for surrounding ones were used to derive plausible ranges (Guriat (Saudi Arabia), Queen Alia International Airport (Jordan) and Safawi (Jordan)).

In addition, the validated model forms the basis from which to explore design alternatives and shelter operation strategies (table 1):

- ‘Orientation’ and ‘Shading’ focus on a different arrangement of shelter units that alters their solar heat gains globally.
- ‘Insulation thickness’, ‘Thermal mass’, ‘Thermal mass location’, ‘Infiltration’ and ‘Opening effectiveness’ address different design specifications. In the case of

thermal mass, the baseline is the original lightweight construction (IBR sandwich panel with 15mm insulation). The alternative is a heavyweight envelope with a decrement delay[1] of 12h which aims to take advantage of the diurnal swing in desert climates.

- 'Occupancy' and 'Ventilation strategy' assume the same building characteristics but with different occupancy densities or operation modes. A minimum ventilation of $8l\cdot s^{-1}\cdot p^{-1}$ is considered despite the purge ventilation strategy.

Human thermal models

Refugees do not have access to electricity and the main cooling strategy at building level is natural ventilation. The social survey highlighted that coping mechanisms against heat were mainly to shower, to pour water onto themselves with their clothes on and to spray water on the floor. Other parameters such as clothing were adjusted within certain ranges (average summertime clothing insulation between 0.50±0.07clo (M) and 0.93±0.05clo (F)).

Annual overheating is first evaluated via the adaptive comfort model according to ASHRAE Std. 55 2013 (ANSI/ASHRAE 2016), calculating the running mean as the exponential moving average of outdoor temperature, $T_{rm}(\alpha=0.8)$. Discomfort is evaluated trough the temperature difference between the internal operative temperature and the adaptive comfort upper limit ($T_{lim} = 0.31\cdot T_{rm} + 21.3$). Illustrative limits of discomfort are established at 1% and 3% of the annual occupied time since the ASHRAE model does not suggest one. These values are on the lines of European recommendations (BSI 2007; CIBSE 2013) for temperature differences greater than 1K over the adaptive comfort upper limit.

Heat stress is evaluated through two rational thermal physiological models:

1. Pierce 2-node model: This is the updated version of the Pierce 2-node model (Gagge et al. 1971; Fountain & Huizenga 1997). It considers air and radiant temperatures, relative humidity, activity level, work efficiency, clothing and air velocity. The 'discomfort index' (DISC) is used to report heat strain as this index normalizes the effect of the inputs on the thermoregulatory system in a 7-point scale (-3 severe cold strain, 0 neutrality, +3 severe heat strain).
2. Predicted Heat Strain (PHS): ISO standard method (BSI 2004) to evaluate heat strain through required sweating and changes in the deep body temperatures presented by Malchaire et al. (2001).

The Pierce 2-node and the PHS models present technical barriers for their adoption in building simulation studies. Although the first is included in EnergyPlus, the user must introduce time-varying values for air speed and certain assumptions cannot be adjusted. The PHS is not part of building simulation suites and its implementation is computationally intensive for annual studies in large parametric analyses.

To overcome these issues, the models were implemented and validated numerically in a standalone application. For this study, the air speed has been estimated through the time-varying natural ventilation air flow divided by the cross-section of the shelter unit and fed into the calculation of operative temperatures (ASHRAE 2013). Regarding clothing, the aforementioned average of 0.93clo has been considered as a representative value.

[1] The time difference between external and internal peak temperatures in a 24-hour period.

Results and discussion

Current shelters

The results for extrapolated annual overheating in current shelters under typical weather conditions are presented in figs. 4 (discomfort), 5 (Pierce 2-node) and 6 (PHS). For the first two, severity is reported in the X axis (binned) and duration is reported in the Y axis for the three locations[2]. The PHS model follows an independent assessment scheme.

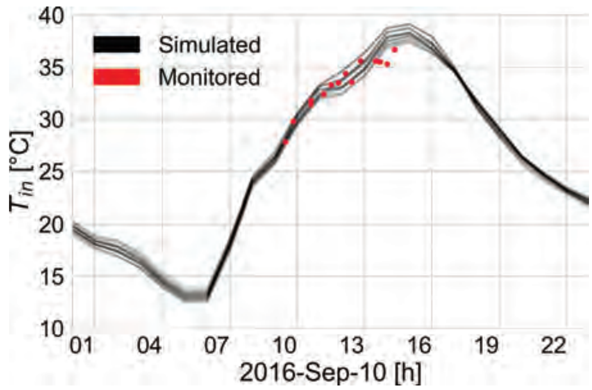

Figure 3. Current shelters: example of measured indoor conditions (red, n=14) and simulated models (black, n=72) over 24 hours.

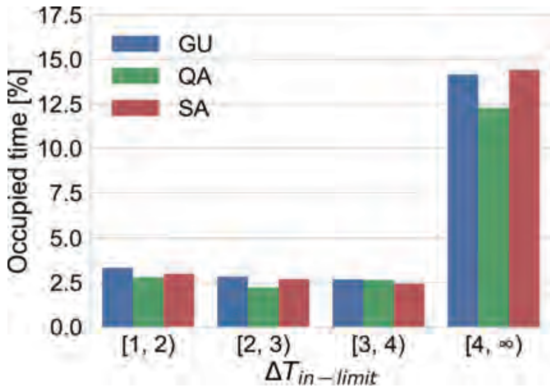

Figure 4. Current shelters: extrapolated annual overheating according to the Adaptive Thermal Comfort model (ASHRAE Std. 55)[2].

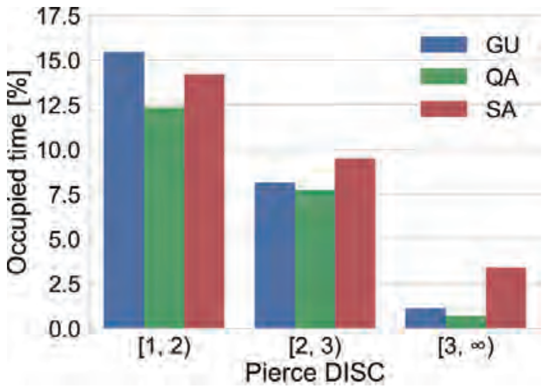

Figure 5. Current shelters: extrapolated annual overheating according to Pierce 2-node DISC[2].

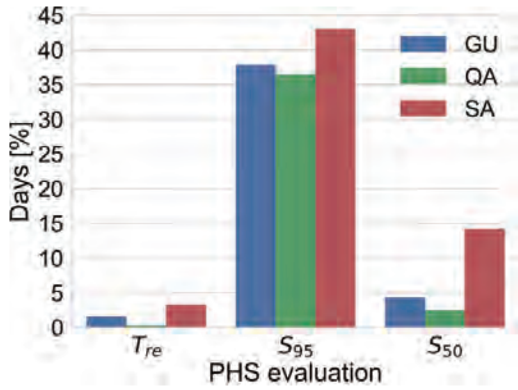

Figure 6. Current shelters: extrapolated annual overheating according to PHS[2,3] (n.b. Y axis scale).

The discomfort evaluation (fig. 4) shows that the adaptive thermal comfort upper limit is surpassed for more than 20% of the time, well beyond the maximum 1% (annual) or 3% (seasonal) illustrative limits. Of special concern is that more than 12% of the time the overheating is severe ($\Delta T \geq 4$), a trend that is consistent in the three locations considered.

The heat strain measured via the discomfort index in the Pierce 2-node model (fig. 5) indicates an unacceptable indoor environment from the physiological perspective, with a cumulative average greater than 20%. Unlike the previous, votes follow a diminishing progression towards greater strain. However, durations in the severest bins are well beyond what is deemed appropriate for comfort conditions.

The PHS provides greater insights to evaluate potential health risks. Here, each day of the annual building simulation is considered independent and simulated from 9 to 17h (a best-case scenario since physiological indicators are reset for the following day). Fig. 6 shows the percentage of days where limits for each variable are surpassed. Despite

[2] GU: Guriat (Saudi Arabia), QA: Queen Alia International Airport (Jordan), SA: Safawi (Jordan).

[3] T_{re}: Rectal temperature limit surpassed, S_X: Sweating limit surpassed for X% of the population.

occupants were considered adapted to hot conditions and able to drink water as required, the water loss due to sweat is evaluated excessive for 95% of the population for more than a third of the year and greater than 2.5% for the mean subject. A complementary indicator is the change in rectal temperature. Here, the upper limit of 38°C (ΔT=+1.2K) is surpassed in the three locations (≈0.28%, one day, for Queen Alia). Therefore, the evaluation indicates that indoor conditions cause both excessive water loss and changes in the deep body temperature in the refugee shelters under typical weather conditions.

Relative importance of design parameters

The main effects for each of the 23 parameter-case in the 3,072 model variants are presented in fig. 7 for discomfort duration and ranges of internal temperatures in fig. 8. Although this is an overview of performance, it is noticeable how 18 out of the 23 parameter-case span the wide minimum–maximum value range (≈2.5% and ≈20%, respectively). This indicates that shelters can be greatly optimized to cope with the hot desert climate despite the limited passive strategies considered.

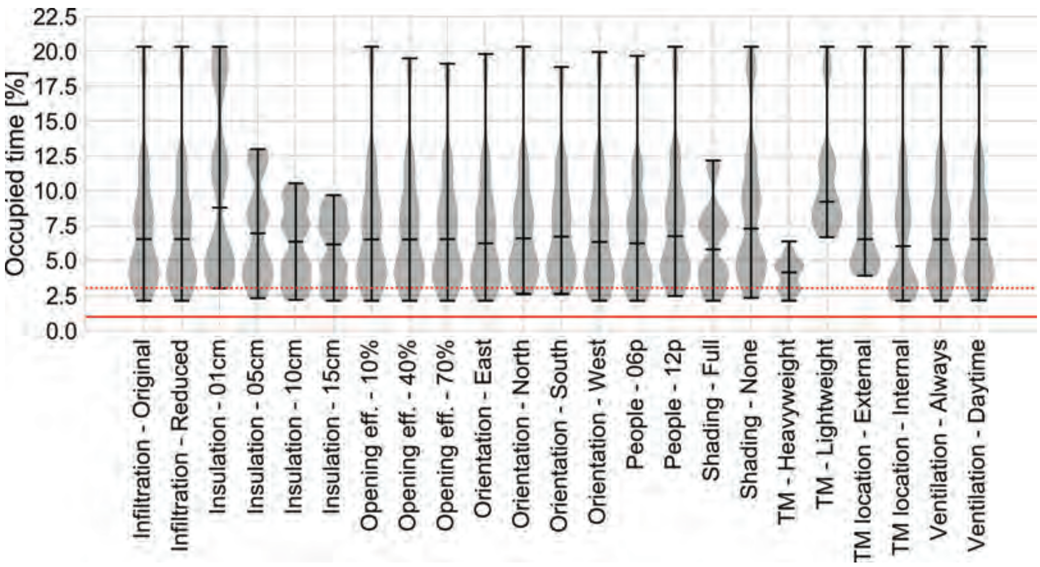

Figure 7. Overheating discomfort in proposals: main effects (plot indicates minimum, median and maximum (black segments) and variable distribution (shaded area); illustrative overheating thresholds in red: 1% and 3%).

Of paramount importance are insulation thickness, thermal mass and shading: they have a determining impact no matter the values of remaining variables. Additionally, they constitute robust solutions that do not depend on occupant behaviours. Changing insulation from 1cm to 5cm onwards almost halves the maximum overheating, although 1cm can deliver 3% overheating if care is taken in every other design parameter. The provision of sufficient thermal mass as to achieve a 12h decrement delay proves to be the most effective solution —even for 12-person occupancy (high internal gains)—, whereas the theoretical maximum shading performs similarly to 5cm insulation. Lastly, the fact that external thermal mass scores a minimum of 4% suggest that retrofitting shelter envelopes from the exterior could be an effective overheating countermeasure; notwithstanding, internal thermal mass is preferable.

Table 2. Proposals: best, median and worst cases according to annual overheating discomfort duration.

Orientation	Insulation [cm]	Thermal mass	Thermal mass location	People [p]	Shading	Ventilation	Opening effec. [%]	Infiltration	Overheating time [%]
East	15	Heavyweight	Internal	6	Full	Always	40	Original	2.2
South	1	Heavyweight	External	12	None	Daytime	70	Reduced	6.4
North	1	Lightweight	Internal	12	None	Daytime	10	Reduced	20.3

The best, median and worst cases (table 2) are analysed in the same way as the current shelters. Figure 9 highlights how the best case can diminish overheating duration to 2.2% while avoiding severe overheating (ΔT≥4K). The heat strain (fig. 10) features an equivalent reduction in overheating, with the median model avoiding the range [3, ∞). Lastly, excessive water loss due to sweating can be completely avoided for the mean subject or greatly diminished for the 95% population and changes in the deep body temperature can be kept below the recommended threshold in every case throughout the year (fig. 11).

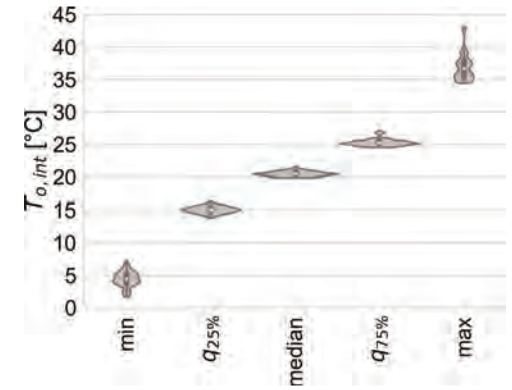

Figure 8. Proposals: indoor operative temperature ranges (n=3072; values computed independently for each case and aggregated into each violin plot).

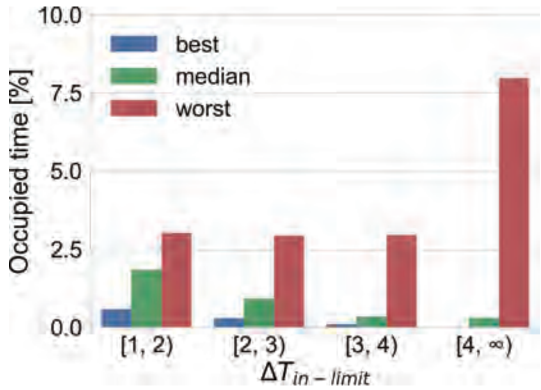

Figure 9. Proposals: annual overheating according to the Adaptive Thermal Comfort model (ASHRAE Std. 55 2013; n.b. Y axis scale).

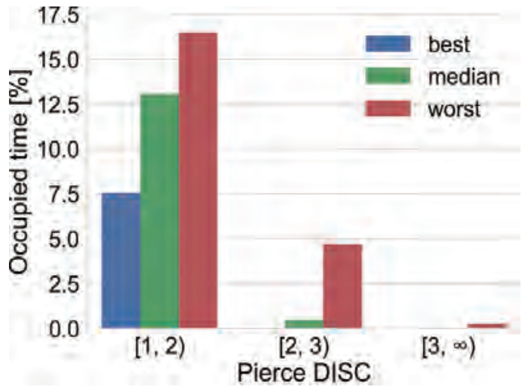

Figure 10. Proposals: annual overheating according to Pierce 2-node DISC (n.b. Y axis scale).

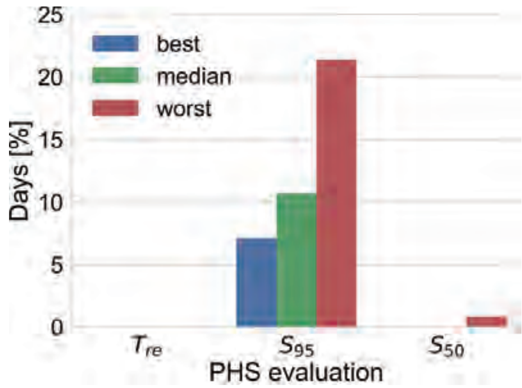

Figure 11. Proposals: annual overheating according to PHS[3] (n.b. Y axis scale).

Conclusions

The provision of adequate shelter for refugees is becoming an even more pressing issue than ever before given the increasing number of people involved worldwide. Owing to different humanitarian crises, refugees are often allocated in camps subject to harsh environments that can represent a threat to their health and wellbeing. Therefore, this paper presented the study of indoor thermal conditions in the Azraq refugee camp (Jordan) to evaluate the annual overheating risk of refugees from a discomfort and health risk perspective. Based on a three-week field study during summertime in the camp, overheating exposure was evaluated through adaptive thermal comfort and physiological models for heat stress. Extrapolated annual conditions via building and human thermal simulation suggest that refugees are subject to overheating for more than 20% of the year, surpassing recommended physiological thresholds for heat stress. Building on the efforts of involved agencies, the study presented a parametric analysis of passive strategies in 3,072 shelter variants. Results indicate that considered measures can reduce overheating to 2.3% of the year, with a drastic reduction in associated heat stress.

Acknowledgements

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Design to Thrive

Contribution of Solar Protection in Windows for Reducing Building Energy Demand in the Climatic Zones of the Spanish Peninsula

María Gavira[1*], Enrique Larrumbide[1] and Virginia Sánchez[1]

[1] Quality in Construction Unit, Eduardo Torroja Institute for construction science, Spanish National Research Council (CSIC), Madrid, Spain.
*mariagg@ietcc.csic.es;

Abstract: The Spanish Building Code establishes in its "Energy saving" document, limitations on energy demand and consumption for residential building stock. In new residential buildings the energy demand requirements are establihed separately for heating and cooling. The heating demand limitation is determined based on the useful surface of the living spaces of the building, and winter climatic zone, while the cooling demand limitation is set based on the summer climatic zone. To achieve compliance with the regulation requirements, guide values of the characteristic parameters for the thermal envelope depending on the climatic zone are given: thermal transmittance of the roof, walls, floor and windows. To achieve compliance with regulatory requirements in accordance with these recommendations without the introduction of any design element you may need a significant thickness of thermal insulation in some climate zones, making the solar factor of the glass a crucial design element. The aim of the study is to analyze the energy demands of the building models chosen among different residential building types and representative climatic zones, with recommendations established by the Spanish Building Code to achieve compliance with regulatory requirements. Subsequently, it is proposed to place sunscreens on windows during the summer period, analyzing the reduction of cooling demand which will allow design flexibility indicators for the thermal envelope recommended in the Building Code, also complying with regulatory requirements.

Keywords: Energy saving, solar protection, residential building, building regulation

Introduction

Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings, establishes a tightening of the minimum energy performance requirements for buildings, pursuing more ambitious objectives such as reaching near zero energy buildings.

40% of the total energy consumption in the European Union corresponds to buildings. Therefore, the reduction of energy consumption and the use of energy from renewable sources in the building sector constitute an important part of the measures necessary for reducing the Union's energy dependence and greenhouse gas emissions. Member States should take the necessary measures to ensure that minimum energy performance requirements for buildings are established in order to achieve optimum levels of profitability.

In this context, the Energy Saving Document (DB HE) of the Spanish Technical Building Code (CTE) is updated in 2013, which includes a limitation on the energy demand of the building separately for heating and cooling. The way of limiting the demand for heating is well studied by the insulation of the building, and the tightness against air infiltrations. The demand for cooling is usually controlled by the parameters of sun protection linked to the windows of the building envelope. But even more effective can be the control of this solar radiation from the outside, blocking it with shading elements.

The solar radiation received by the Spanish peninsula is much higher than that received by other countries of the European Union, as can be seen in figure 1. For this reason, and linked to the temperature increase due to climate change, better adapted solutions in buildings to this conditions should be outline.

In addition, within the peninsula there are varied climates depending on whether we are on the north coast, the peninsular meseta, the Mediterranean coast or the south of the peninsula. A variety of climates are presented to which the architectural solutions must be adapted in the best possible way.

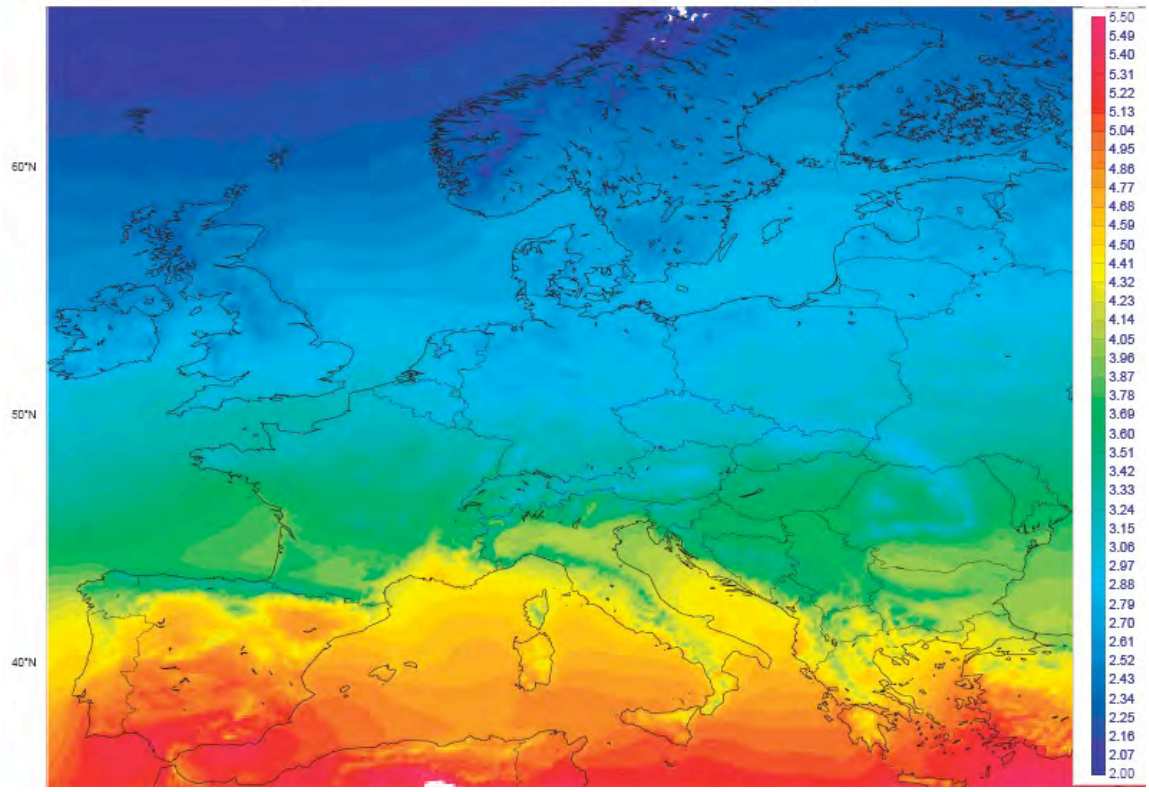


Figure 1. Global mean solar irradiatin in Europe (kWh·m^{-2}·día^{-1})

It is necessary to take into account that a good part of the Spanish territory has zones with severe winters and summers, and in each season will be demanded a different answer against the outside environment from the building. The monthly distribution of solar radiation is not homogeneous throughout the year, the central months of the year receive much more solar radiation than the winter months, so that the sun protection measures should be adaptable to the the building energy demand in every season of the year.

The present study aims to analyze the effect of the windows shading elements on the energy demand of three buildings representative of the private residential building stock in each of the winter climatic zones of the Spanish peninsula, considering those most critical regarding the summer climatic severity.

Methodology and study cases

The analysis of the energy demand is performed based on simulations using the Unified tool Lider-Calener, which is the reference tool for verifying compliance with the requirements of energy saving Spanish Building Code (CTE DB HE).

To perform this study, three types of building have been considered, among the typical housing construction in Spain: a multifamily housing, a single-family house and a semi-detached house as seen in figure 2. The parameters that define the model for each type of building are collected in table 1.

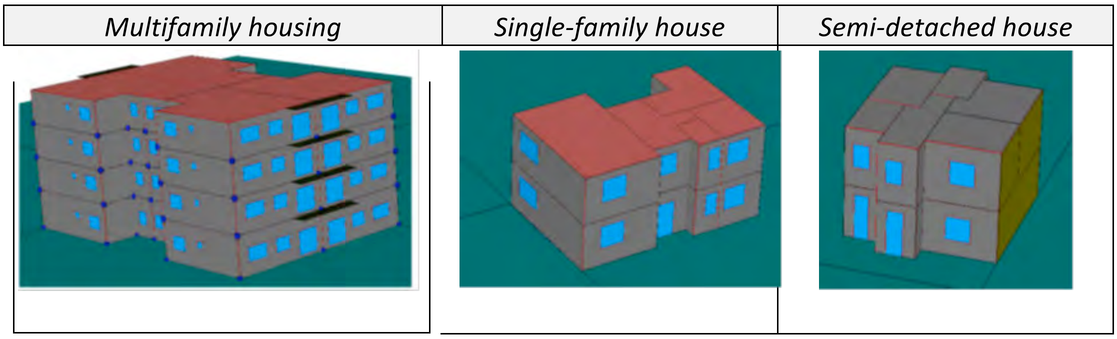


Figure 2. Types of building models

Table 1. Geometric parameters of the building models

TYPE OF HOUSING	LIVING AREA (m^2)	COMPACTNESS (m)	VOLUME (m^3)	ENVELOPE AREA (m^2)	WINDOWS %
Multifamily housing	1674	2,5	5231	2100	16
Single-family house	134	0,9	307	185	14
Semi-detached house	102	1,3	293	214	14

The thermal transmittances of the envelope elements are taken as reference values from the guideline values given in appendix E of the Energy Saving Document of the Spanish Building Code. In any case, some values have had to be reduced in order to achieve compliance with the minimum energy demand requirements.

Table 2. Envelope elements transmitances

Element transmitance ($W/m^2 \cdot K$)	Climatic Zone				
	A	B	C	D	E
U_M	0,50	0,38	0,29	0,27	0,25
U_S	0,53	0,46	0,36	0,34	0,31
U_C	0,47	0,33	0,23	0,22	0,19

To reach the objectives of the work, a series of cases have been set out, varying the parameter of interest, which is the shading coefficient of the awnings for each type of building.

Orientations

The different types of buildings have been analyzed for the East-West orientation as it is the most unfavorable for the overheating of buildings in summer season. In the North-South orientation, lower cooling demands are obtained than in the studied orientation.

Climatic Zones

To analyze the influence of the awnings in the energy demand, the building models has been studied in five representative climatic zones according to the Spanish regulation, corresponding to the five winter climatic zones in the peninsula, with representation of the most severe summer climatic zones, E1, D3, C4, B4 and A4.

The Spanish Building Code defines several climatic zones to establish the energy requirements for buildings. This climatic zonification corresponds to the division of the Spanish territory depending on the winter climatic severity and the summer climatic severity, as seen in chart of figure 3. An approximate distribution of the Spanish peninsula in winter climatic zones can be seen in the map of figure 3.

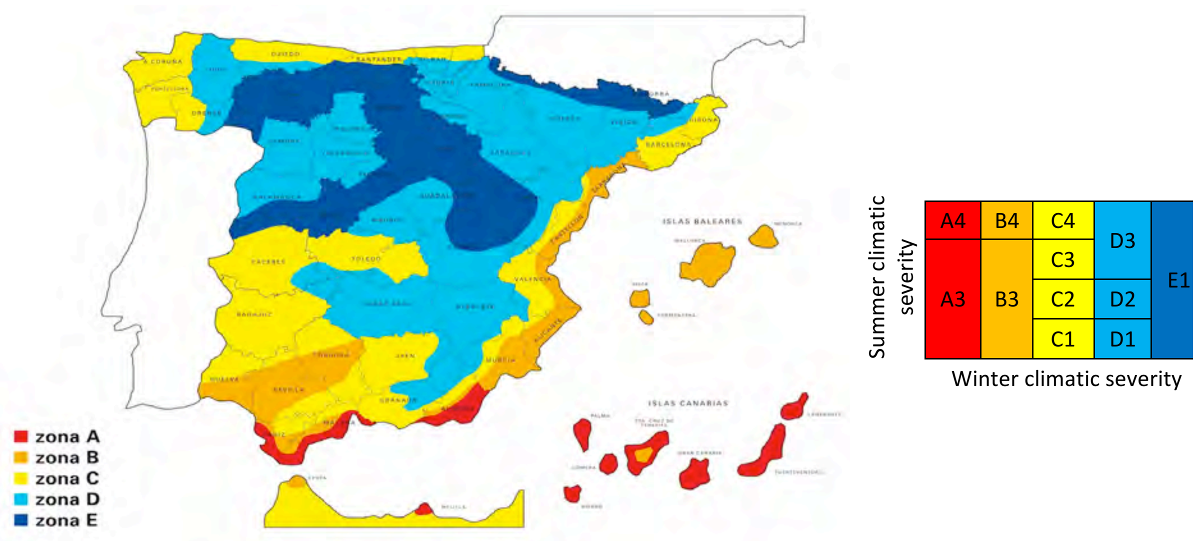
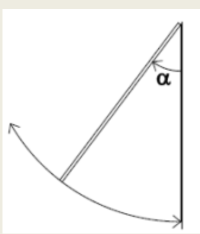


Figure 3. Spanish climatic zones

Shading elements

For the different buildings studied, opaque fabric awnings with different inclinations have been used as shading elements. The values of the shading coefficient corresponding to each awning inclination are given in Table 3.

Table 3. Shading coefficients

	Angle	Orientation	
	**α**	**SE/S/SW**	**E/W**
	30	0,02	0,04
	45	0,05	0,08
	60	0,22	0,28

Results

The thermal transmittance values used have been adjusted to meet the minimum demand requirements established in the Energy Saving Document of the Spanish Building Code. To evaluate the average performance of the envelope, the K value is defined as a weighted average of the transmittances of the elements that compose it (facade, roof, floor, windows) in relation to the area of the element with respect to the global envelope area.

In the graph of Figure 4, it can be observed how the lowest values of the global K coefficient are established for the areas with coldest winter weather severity, E, D and C. If we compare the values of K defined for each building, we can observe that the single-family house has, in general, the lowest K values, the most demanding, while the multifamily housing is the one that usually has a higher K value. This is related to the compactness of each building, where the lowest K value corresponds to the building with lower compactness and the highest value of K corresponds to the building with higher compactness. Indeed, the compactness of the building, determines the amount of envelope surface exposed to the outside, and with it, the greater need of a good envelope insulation to avoid energy losses.

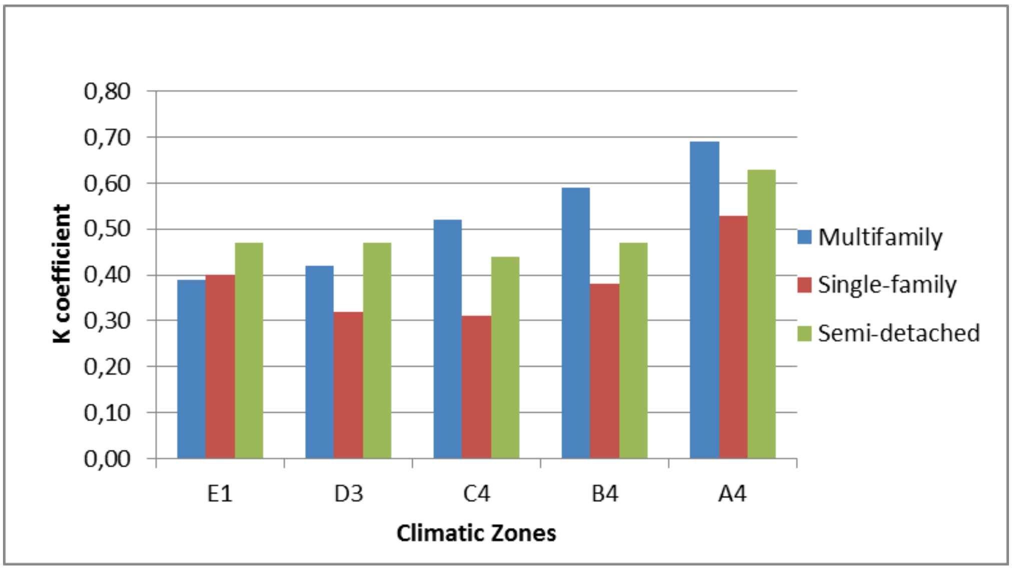


Figure 4. K coefficients of the buildings analyzed in each climatic zone

Multifamily housing

In Figure 5 we can observe the energy demands obtained for the multifamily housing in the different cases studied. It can be seen that, through the placement of awnings, the cooling demands are below the value of 15 kWh/m^2·year in all climatic zones. It can also be observed that the values of cooling demand with awnings at different inclinations are very close, there is little difference of demand between them.

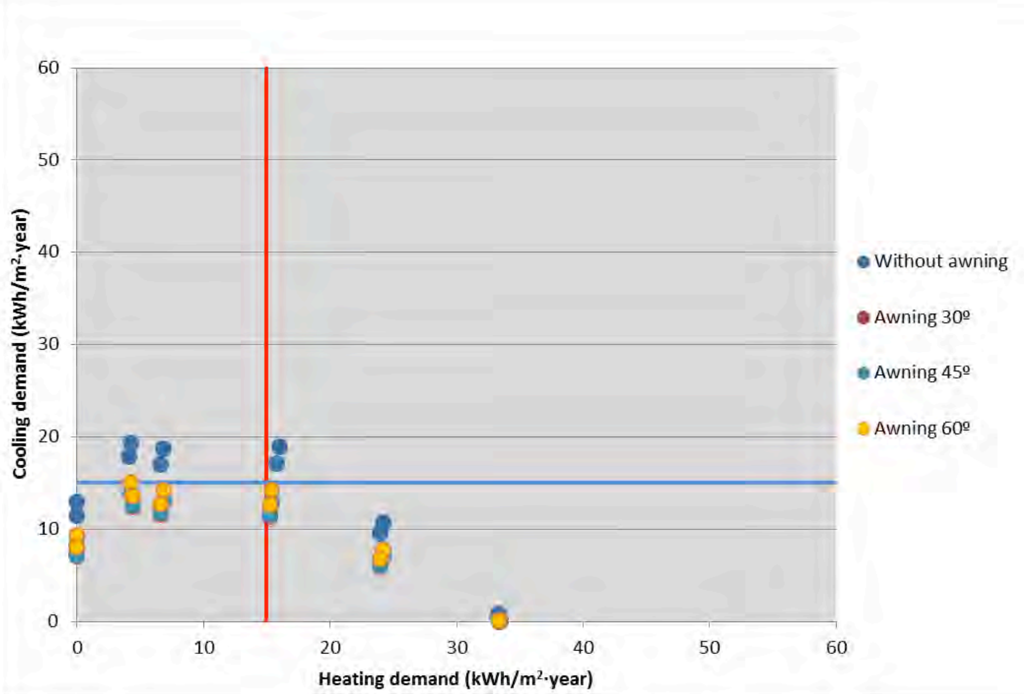


Figure 5. Multifamily housing energy demands

Single-family house

As in the case of the multifamily housing, the cooling demands of the single-family house with awnings are below the value of 15 kWh/m^2·year in all climatic zones, with slight differences between the different types of awnings.

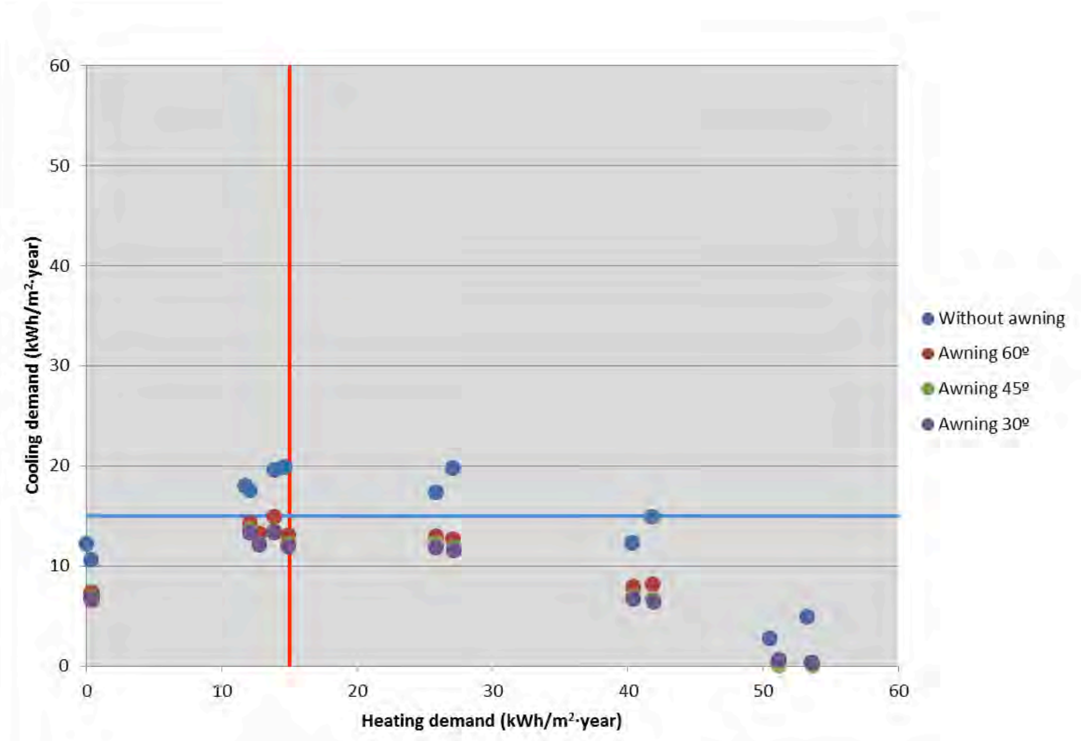


Figure 6. Single-family house energy demands

Semi-detached house

In the semi-detached house, as in the previous cases, the placement of awnings in windows causes the cooling demands to be less than 15 kWh/m^2·year, even in some of the simulated cases without awning, only with the solar protection of window glass.

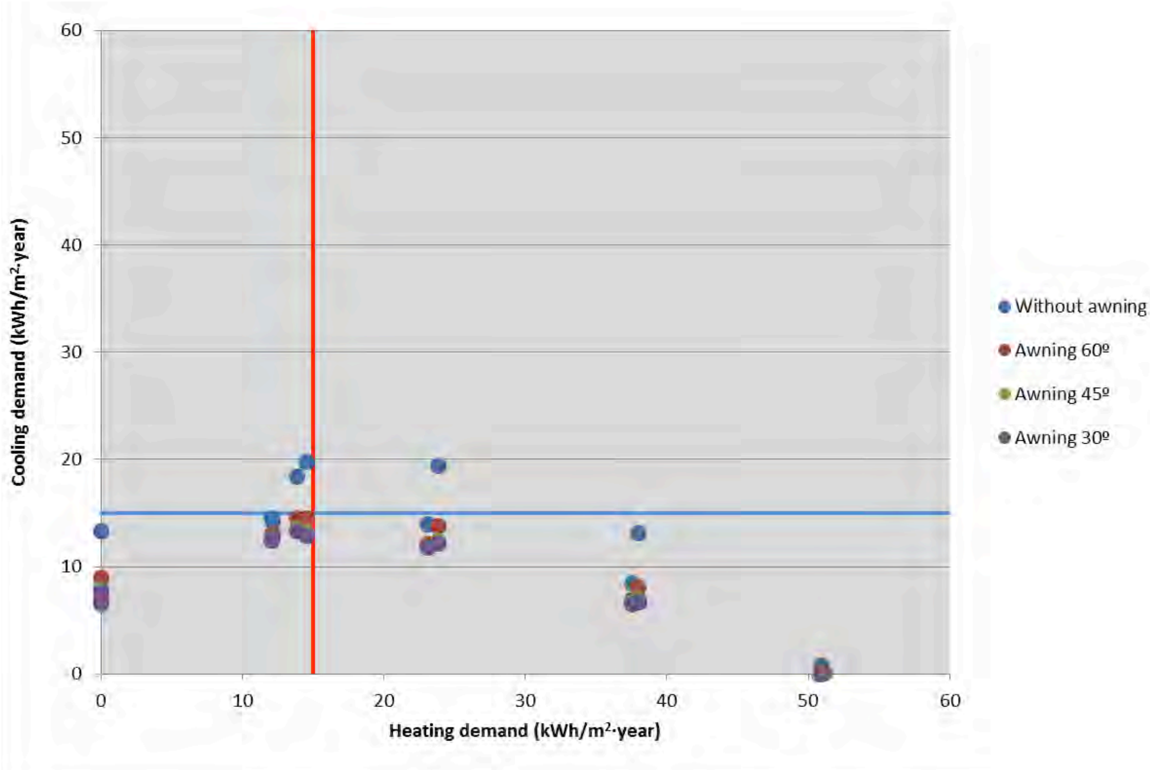


Figure 7. Semi-detached house energy demands

Discussion and conclusions

The provision of awnings in south, east and west windows orientations causes a significant decrease in the cooling demand. This reduction is already obtained with the awning at a higher inclination, 60 °, which makes less shading but sufficient to block the radiation that causes the increase of internal loads and the consequent increase of cooling demand.

The differences in cooling demands between the different inclinations of awnings is negligible, with the inclination of 30 ° being the one that provides the most shade and a lower value of cooling demand. In all cases, it is observed that with awnings at 60 ° the demands obtained are already less than 15 kWh/m^2·year, for all orientations and climatic zones considered.

It is also noted that in cold climatic zones, zones D3 and E1, the values of the cooling demands are zero or very low and less than 15 kW · h / m2 · year, so awnings becomes not so necessary, but recommended in D3 for the severe summer.

Recommendations for regulations

In view of the results, and taking into account the varied climate that we have in the Spanish peninsula, it is interesting to establish recommendations adapted to the climatic zone in which the building is located. The shading elements can be optional in cold climatic zones, such as zones E and D, mainly in combination with low summer weather severity, such as climates 1 or 2.

The rest of climates characterized by summers 3 and 4, must have shading elements in windows or façade hollows, with the possibility of adapting them to the time of year, in order to block solar radiation only in those months when we are not interested because of the high external temperatures.

Future lines

To adapt the required regulatory requirements to buildings in relation to their energy performance, it is necessary to update the climatic data with which to carry out the design and sizing. The climate change observed in recent years by higher temperatures compared to previous averages, makes it necessary to adapt the buildings to these new conditions, mainly in the warmer areas that occur in the climate of the Spanish peninsula.

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Design to Thrive

Heat stress in hospital ward spaces: An investigation on a naturally ventilated hospital building in UK

R. Giridharan[1]

[1] Kent School of Architecture, University of Kent, Canterbury, United Kingdom.
email: G.Renganathan@kent.ac.uk

Abstract: In the context of climate change, there is increasing concern about the likelihood of overheating in hospitals in UK, especially in buildings which are not mechanically cooled. A number of studies have examined this issue in different hospitals in UK. On most occasions these studies have focused on overheating and evaluated the performance of the spaces using adaptive thermal comfort criteria. Adaptive criteria is not a good indicator of actual heat stress. Further, the adaptive criteria cannot be applied to spaces that have no operable windows. However, in hospital, substantial number of spaces are without windows, especially nurse stations. This paper will assess the heat stress in ward spaces using Wet Bulb Globe Temperature (WBGT) heat index in order to explain the occupant's vulnerability while looking at the potential of combining this index with adaptive thermal comfort criteria (BSEN15251). The paper will focus on naturally ventilated Runcie ward building at St Albans city hospital and assess its thermal performance for summer 2011. During summer 2011, the maximum WBGT varies between 21.5°C and 23.8°C while the minimum was between 13.6°C and 14.3°C. The paper proposes WBGT of 23°C as a heat stress threshold for sick and vulnerable.

Keywords: Adaptive comfort, Heat stress, Wet bulb globe temperature, monitoring, hospital.

Introduction

During periods of high ambient temperature, hospitals are expected to provide a safe environment for patients, especially during heat waves (NHS, 2011). On most occasions when temperatures are high that hospitals harbour the greatest concentration of vulnerable individuals. However, there is increasing concern about the likelihood of overheating in hospitals in UK, especially in buildings which are not mechanically cooled (Lomas and Giridharan; 2012). The maintenance of thermal comfort in such spaces is critically important and installing air-conditioning in response to climate change is expensive and potentially energy intensive. In this context, during the period 2009-12, the Design and Delivery of Robust Hospital Environments in a Changing Climate (DeDeRHECC) research project investigated the impact of summer overheating in hospital campuses operated by four National Health Service (NHS) Acute Trusts. Some of the findings and possible measures that could be adapted in the Addenbrooke's, Bradford and Glenfield hospital buildings to climate change have been presented elsewhere (Short et al., 2012, Short et al., 2015; Lomas et al., 2012: Giridharan et al., 2013). These papers examined the performance of ward spaces using the BSEN15251, CIBSE and HTM03.

DeDeRHECC research project shows that BSEN15251 is best suited to evaluate thermal performance of the ward spaces. However, the BSEN15251 can only be applied to naturally ventilated buildings with operable windows and mechanically ventilated building without conditioning the air. But, substantial part of hospital spaces do not have operable windows, for example, some nurse stations, internal corridors and consultation rooms. These important spaces cannot be assessed using BSEN15251. Further, although heating is turned off in most hospitals in summer, they tend to come into operation whenever there is cold period (Giridharan et al., 2013). For these days BSEN15251 cannot be applied. Therefore, alternative assessment criteria should be established that could be used to assess all types of spaces in the hospitals, considering that patients visit most of these areas and staffs in these areas also need to be in a comfortable environment to perform their services effectively. In this context, this paper will assess the heat stress in ward spaces using Wet Bulb Globe Temperature (WBGT) heat index in order to ascertain the occupant's vulnerability. The study will also compare the WBGT with the adaptive thermal comfort criteria (BSEN15251) results for the spaces where both criteria could be applied in order to establish the importance of using both systems to assess spaces. For this purpose, this paper focuses on 2011 summer conditions in the Runcie ward building at St Albans city hospital.

Premises for the investigation

The applications and limitations of CIBSE, HTM03 and BSEN15251 for the assessment of hospital spaces have been dealt in detail by Lomas and Ji (2009) and Lomas and Giridharan (2012). The summary of the above assessment criteria are presented in the Table 1.

Table 1: Criteria for assessing internal temperatures in naturally ventilated spaces [Short et al., 2012].

Assessment metric	Source	Criterion	Applicability	Comment
Total hours, dry-bulb temperature over 28°C.	HTM03-01 [2007]	Limiting value 50 hours.	All spaces and buildings.	Weather year to be used in simulations not stated.
Night time hours operative temperature over 26°C.	CIBSE Guide A [2015]	No more than 1% of hours above value.	Sleeping spaces only.	Value based on homes and not health care facilities.
Adaptive comfort Cat. I and Cat II envelopes. Thresholds of operative temperature vary with running mean of ambient temperature.	BSEN15251 [2008]	No more than 5% of hours outside envelope, in any day, week, month or year.	Naturally ventilated buildings with operable windows and mechanically ventilated building without conditioning the air.	Cat I is applicable to spaces with vulnerable individuals, such as wards, Cat II for 'normally' occupied spaces, such as offices, consulting rooms, etc.

Notes

1. The limiting value for a year is 50, 37 (assuming patient is at sleep the whole day) and 438 hours for HTM03-01, CIBSE and BSEN15251 respectively.
2. The*r*e could be few occasional hours where the room heaters could have been kept on based on individual preference. So the results should be viewed keeping this limitation.

Among the above said criteria, only BSEN15251 is based on adaptive principle. It is basically on the principle that people are sensitive to the environment and they make themselves comfortable by making adjustments to clothing, activity and posture (Nicol and Humphreys, 2007). Most importantly standard's scope includes hospital and advocates the application Cat I (fig. 1) band for 'spaces occupied by very sensitive and fragile persons with special requirements like, handicapped, sick, very young children and elderly persons (BSEN, 2008)'. As per the standard at a running mean of 30°C, the sick person is able to adapt an indoor temperature of 31°C. The author is of the opinion that this is not a practical limit. Therefore, within 'Cat I', there should be shorter range. However, what is best about adaptive criteria is that it is easy to use. The BSEN15251 requires hourly monitored indoor and outdoor temperature for the assessment. Monitoring hourly indoor temperature is relatively easy compared to complex parameters that one need to monitor to use other thermal comfort indexes. Therefore, BSEN15251 widely used for design and assessment of hospital spaces. Another drawback of this standard is that it cannot be applied to spaces that do not incorporate windows. However, in hospitals with deep plans there could substantial amount of such spaces. Further, one must also take into account that a person may continue to stay safe in a space that is considered to be as uncomfortable in terms of adaptive standard, as long as that person is not subjected to heat stress (Holmes et al., 2016). This could be true for a healthy person but not for a sick and a vulnerable person. However, it is still important to have an assessment criteria or index range that could be applied to all the spaces in hospital. In this purpose, this paper proposes Wet Bulb Globe Temperature (WBGT) heat stress index. This index was originally developed by the US military and subsequently applied to other work places (NEHC, 2007; OSHA, 2016).

The indoor WBGT (in ^{o}C) index (Eq-1) is a function of natural wet bulb temperature (T_{nwb} in ^{o}C) and black globe temperature ($T_{g\ in}$ ^{o}C) (Lemke and Kjellstrom, 2012). Measuring globe temperature in a functional ward is near impossible considering the clinical constraints one need to face. However, Lemke and Kjellstrom (2012) have validated a simplified equation (Eq-2) proposed by Bernard and Pourmoghani (1999) for the purpose of indoor assessment using psychrometric wet bulb temperature (T_{pwp} in ^{o}C), dry bulb temperature (T_a in ^{o}C) and air speed (V in m/s). This index assumes that occupants are healthy adults.

$$WBGT_{ind} = 0.7T_{nwb}+0.3T_g \qquad \text{Eq-1}$$

$$WBGT= 0.67T_{pwp} +0.33\ T_a-0.048\log_{10}V(T_a-T_{pwp}) \qquad \text{Eq-2}$$

According to Holmes et al., (2016) psychrometric wet bulb temperature could be generated using the equation proposed by Stull, (2011) i.e. T_{pwp} equal to T_w:

$$T_w= T_a\mathrm{atan}(0.151977(RH+8.313659)^{1/2})+\mathrm{atan}(T_a+RH)-\mathrm{atan}(RH-1.676331) + 0.00391838(RH)^{3/2}\,\mathrm{atan}(0.023101RH)-4.686035 \qquad \text{Eq-3}$$

The Eq-2 assumes indoor air temperature is equal to indoor radiant temperature. On most occasions, what is measured in a low air speed hospital environment is not air temperature, but indoor operative temperature i.e. combination of air and radiant. By and large, in low air speed hospital environments, this is influenced by radiant component. Lemke and Kjellstrom, (2012) have validated this equation (Eq-2) up to an air speed of 3m/s. However, this equation is not validated for hospital environments. This index advocates a threshold of 31^{o}C (figure 1) and is applicable for work places, more specifically, industrial work places, where healthy people are performing tasks. This 31^{o}C could be achieved with various combination of temperature and relative humidity (RH). This threshold value, at 100% RH, meets top of the BSEN15251 adaptive Cat II upper limit (figure 2). Therefore, this is not the appropriate threshold for sick. However, Holmes et al., (2016) are of the opinion 28^{o}C could be the threshold for below average healthy people (figure 1). But this has not been validated for a hospital environment. Further, there is big difference between below average healthy and a sick person. Therefore, the threshold needs to be brought down further. On the other hand, for outdoor, the threshold is 23^{o}C (NEHC, 2007) i.e. at this point hot weather practices will be activated. Although this is the initial warning point for outdoor, one could argue this as the threshold for sick and vulnerable by assuming that stress factor felt by healthy individual at WBGT of 23^{o}C (outdoor) will lead to severe health implications for sick person under naturally ventilated hospital (low air speed) indoor conditions. This paper will apply this proposed limit and assess critical ward spaces. The intention is not to validate WBGT of 23^{o}C, but to establish a starting point for further investigation. Further, successful validation could help to narrow down the adaptive comfort band to a range that is applicable for sick people.

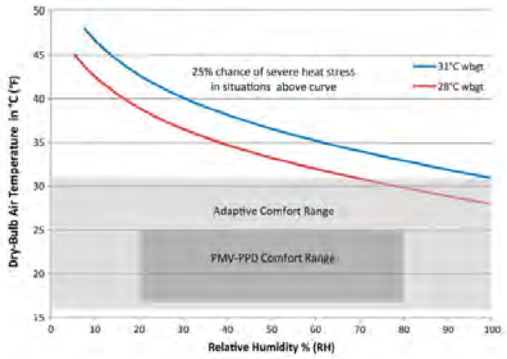

Figure 1: Indoor WBGT (0.3 m/s) and its relationship to BSEN 15251 adaptive threshold (source: Holmes et al., 2016)

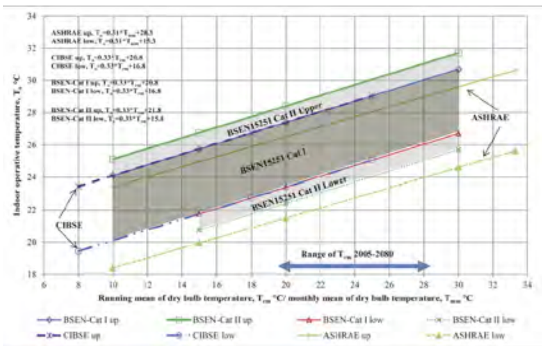

Figure 2: Comparison of adaptive thermal comfort standards (source: Lomas and Giridharan, 2012).

Case study description

The DeDeRHECC project monitored Runcie (wards), Moynahan (wards) and Gloucester wing (consultation) at St Albans city hospital between June 2010 and September 2011. This paper focuses on Runcie ward levels 1 and 3 (Figures 3 & 4) and limit its discussion to summer 2011. This is a three storeyed traditional masonry construction (102 mm brick work (outer leaf)-50 air gap- 50mm mineral fibre insulation-100 medium density block work) building with a concrete tiled pitched roof on timer trusses (with 100 mm mineral fibre insulation). Building is naturally ventilated with perimeter radiator heating. In the bed bay areas, especially in single bed rooms, it is possible to control the radiator through 'on/off' valves. The windows are made of timber frames. Level 1 houses the physiotherapy section while level 3 is elderly care section.

Although loggers are placed in 8 spaces, all the loggers did not measure both temperature and humidity. However, each space had at least one logger that measured both temperature and humidity. The paper will focus on these measurements since WBGT needs both temperature and humidity. So this paper will limit the discussion to loggers 2 (MB102) and 5 (NS) in level 1, and loggers 1(MB101), 4 (MB202), 5(CD01), 6 (SR01) and 7 (SB101) in level 3.

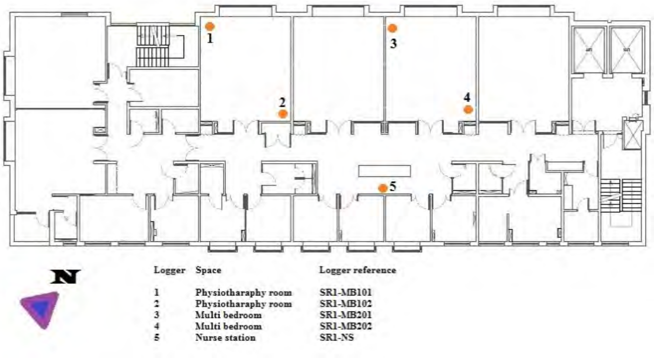

Figure 3: Logger locations in Runcie ward level 1

Figure 4: Logger location in Runcie ward level 3

Results and analysis

The summary of the performance during summer 2011 is presented in Table 2. The mean daytime temperature in the above mentioned spaces were between 22.5^{o}C and 24.0^{o}C. Maximum temperature of 29.0^{o}C was observed in the staff rest room. The maximum relative humidity in the observed spaces ranged between 68.3% and 76.6%. In both levels, circulation, and nurse station and related areas were warmer than bedrooms. MB202 was warmer than MB101. This could be attributed to the air flow i.e. M101 is closer to the window while MB202 is located at the inner most area. However, this change of location did not have an impact on the night time mean temperature since windows were shut. But in terms of CIBSE night time sleeping criteria MB202 exceedance was more (double) than MB101. Therefore, window had an impact in terms of duration of exceedance. Overall, only MB202 marginally exceed the CIBSE night time criteria but all the spaces were within the BSEN15251 Cat I threshold. In terms of HTM03 all the spaces, including nurse station, corridor and staff rest room were within the threshold.

The WBGT values for the spaces were calculated using Eq-2 considering an air speed of 0.1 m/s. The study assumes a low air speed, considering the HTM55 recommendation of 100mm window opening. In the past, during the hospital modelling work, author has observed 0 to 22 ach for summer period in naturally ventilated ward spaces with100mm window opening, however on most occasions it is less than 3ach. Considering the size of the window openings in wards, air speed on most occasion will be less than 0.3 m/s. This value is in line with the air speed recommended for Ultra Clean Ventilation i.e. 0.2 to 0.3 m/s (HTM03, 2007). Further, differences in WBGT for the air speeds of 0.1 m/s and 0.3 m/s is very marginal.

Table 2: Comparison of internal temperatures measured between 1st May and 30th September, 2011, with BSEN15251, CIBSE and HTM03 overheating criteria and Wet Bulb Globe Temperature (WBGT): Runcie Ward Building, St Albans City Hospital.

Space	Maximum $WBGT_{ind-av0.1\ m/s}$ °C	Minimum $WBGT_{ind-av0.1\ m/s}$ °C	Maximum temp °C (24 hours)	Minimum temp °C (24 hours)	Mean daytime temp °C (7:00 to 20:00)	Mean night time temp °C (21:00 to 6:00)	Maximum diurnal range (K)	Maximum relative humidity %	Minimum relative humidity %	H HTM03: Hours over 28 °C (24 hours)	CIBSE: Hours over 24/26 °C (21:00 to 6:00)	BSEN15251:Hours over Cat I / Cat II upper
Level 1												
Multi bedroom (SR1-MB102)	21.5	14.3	25.5	20.1	22.5	22.3	3.3	69.6	21.7	0	29/0	2/0
Nurse station (SR1-NS)	23.0	15.3	27.7	21.8	23.7	23.6	4.2	71.0	19.8	0	NA	NA
Level 3												
Single bedroom (SR3-SB101)	22.9	14.9	28.0	20.5	23.9	23.2	4.1	76.6	17.3	1	256/15	105/09
Multi bedroom (SR3-MB101)	22.6	14.9	27.5	21.2	23.7	23.5	2.9	68.3	19.9	0	365/17	41/05
Multi bedroom (SR3-MB202)	23.1	14.0	28.0	20.0	23.6	23.5	3.7	69.4	22.0	2	360/38	97/18
Corridor (SR3-CD01)	23.0	14.5	28.3	21.2	24.0	23.8	2.8	70.2	20.1	7	NA	NA
Staff restroom (SR3-SR01)	23.8	13.6	29.1	20.0	23.9	23.2	5.1	76.6	17.3	21	NA	186/50

Notes (Table 2):

1. Total number of hours: 3672. Total number of night time (21:00 to 6:00) hours: 1530
2. The study assumes that all the overheating takes place during May to September. Therefore, limiting overheating values for the monitored period are: HTM03, 50 hours over 28 °C; BSEN15251, 438 hours above category upper threshold and CIBSE, 37 night time hours over 26°C.
3. Levels 1 and 3 are physiotherapy and elderly care respectively.

The maximum WBGT varies between 21.5°C and 23.8°C while the minimum was between 13.6°C and 14.3°C. The spaces NS, MB202, CD01 and SR01 have crossed the proposed WBGT threshold of 23.0°C. The spaces SB101 and MB101 are marginally below the proposed threshold. MB202 and CD01 have one hour above WBGT of 23.0°C for daytime while NS has one hour for night time. SR01 has 9 daytime hours above WBGT of 23.0°C. Overall, 99% of the time, spaces were below WBGT of 23.0°C.

However, it should be noted that there were 9, 5, 18 and 50 hours above BSEN15251 Cat II for SB101, MB101, MB202 and SR01 respectively (Table 2). BSEN15251 says that 5% of occupied time the space could be above the category threshold, however it does not clearly state whether this exceedance could cross the next category i.e. can the Cat I exceedance cross Cat II? In the case of MB202 and SR01 there were few hours above Cat III (Figures 5 & 6). In principle, this is very critical for sick people. However, the author is of the opinion that exceedance is acceptable if it does not cause heat stress. The exceedance above Cat II in

MB202 and SR01 take place around WBGT of 23.0^{o}C. Similar trend was found in SB101 and MB101. Therefore, these exceedances were acceptable. At the same time, some may consider this as a conservative figure in terms of energy savings and carbon reduction, and speculate another 1 or 2 degrees higher as suitable value. But, definitely WBGT of 28.0^{o}C will be an extreme point for sick people. Therefore, further in depth research is required to validate an appropriate WBGT heat index for patients. However, from above findings it is clear there could be occasions, especially in the future, where there will be periods within or above Cat I but under severe heat stress conditions. Such scenarios could take place when the running mean temperature exceeds 22.0^{o} C (refer figures 1, 5 & 6 together). Similarly, one needs to look at the lower limit as well i.e. the cold stress. In essence, future research should establish heat and cold stress boundaries for sick people within the BSEN15251 Cat I adaptive band.

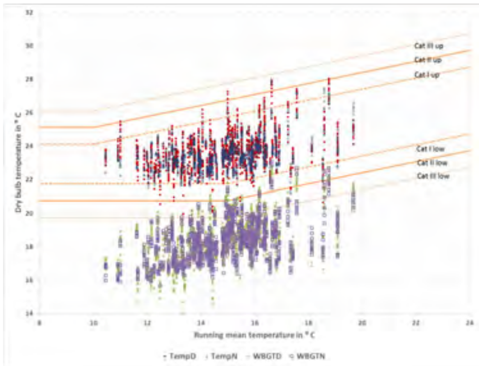

Figure 5: Internal temperature measured in MB202 is compared to BSEN15251 categories. The WBGT is also potted against corresponding running mean temperature for the purpose of comparison.

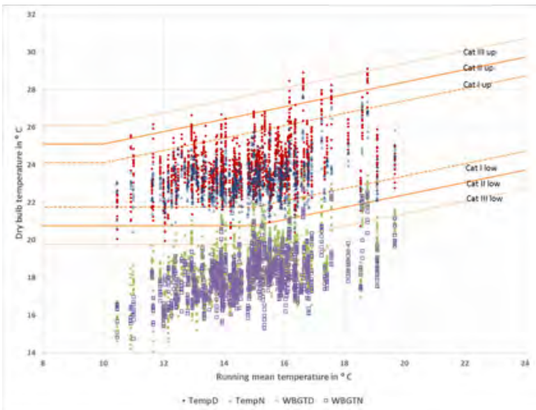

Figure 6: Internal temperature measured in SR01 is compared to BSEN15251 categories. The WBGT is also potted against corresponding running mean temperature for the purpose of comparison.

Conclusion

The study assesses the thermal performance of Runcie ward building at St Alban city hospital by applying BSEN15251 adaptive criteria and WBGT heat index. During summer 2011, the spaces were within the threshold of BSEN15251 Cat I. Overall, maximum WBGT of all the spaces were between 21.5^{o}C and 23.8^{o}C. The paper outlines the convince of using BSEN 15251 for hospital environmental performance analysis while highlighting the importance of combining WBGT heat stress index into the analysis.

In principle, the spaces should not be considered comfortable for patients if the temperature exceedance hours are within BSEN15251 threshold but the temperature values lead to maximum heat stress. This study proposes WBGT of 23.0^{o}C as the maximum heat stress for patients and establishes a case for validation of this through in depth research in the future.

Acknowledgement

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The Inadvertent Consequences of a Bright Idea: An Experimental Study of Reflective Roofing

Elizabeth Grant[1], Stephen Werre[2] and Kenneth Black[1]

[1] Center for High Performance Environments, School of Architecture + Design, Virginia Polytechnic Institute and State University, Blacksburg, USA, elizabeth@vt.edu;
[2] Research & Graduate Studies, Virginia-Maryland College of Veterinary Medicine, Blacksburg, USA

Abstract: There is presently a conversation in the roofing design community about the potentially adverse effects of broadly implementing reflective white roofing on projects irrespective of climate, microclimate, or building-specific geometry. These effects include the winter heating penalty, difficulty with drying of wetted roof assemblies, and the potential for overheating of building elements atop and adjacent to white roof surfaces. The research described in this paper contributes to the literature documenting the effects of roof surface reflectivity on air temperatures above roofs and on mechanical and electrical equipment components located above them. It also documents the potential thermal consequences of installing white roofs adjacent to south- and west-facing opaque and glazed facades. An experiment was undertaken to determine the different thermal effects induced by black ethylene propylene diene monomer (EPDM) and white thermoplastic polyolefin (TPO) single-ply roof membranes in a low-slope roof application in ASHRAE Climate Zone 4. This paper presents statistically-analyzed findings from data collected on two sunny days in September and October of 2016 and compares them to results from a previous data set collected in March, May, and August of 2016. Conclusions are offered regarding the implications of these findings for architects and other designers.

Keywords: roof reflectance, cool roofs, single-ply roof membrane, building envelope, roof design

Introduction

White, reflective roofs have gained a great deal of popularity in recent years. These "cool" roofs, which are characterized by both high solar reflectance and high thermal emittance (Akbari & Konopacki, 2005), purport to reflect heat upwards and away from buildings, preventing them from overheating. They, along with vegetated roofs, have been named by green building rating systems such as the US Green Building Council's Leadership in Energy and Environmental Design (LEED) program as a preferred strategy to mitigate the urban heat island effect. Many jurisdictions have gone so far as to legislate them on new buildings and retrofit projects through adoption of ASHRAE Standard 90.1 (2013).

Within this context of widespread approval, several groups have challenged the assumption that white reflective roofs are appropriate for all building types and locations. While cool roofs are known to provide energy benefits during the cooling season, there has been debate about the extent of their negative effect in the winter months, called the "heating penalty", which is explored with tools such as the Roof Savings Calculator (Miller, New, Huang, & Erdem, 2010). Ibrahim (2013) has also argued that cool roofs may not be appropriate for colder climates because of concerns relating to condensation risk and associated biological growth. A paper by Jacobson and Ten Hoeve (2012) widely cited in roofing circles suggests through a simulation that if all existing roofs were replaced with cool roofs, there would actually be a net increase in global temperature.

Three studies have focused on the building-scale impacts of cool roofs. Ibrahim (2013) found that that air temperatures were typically higher above white TPO roofs than black EPDM roofs. Dupuis (2013) reported that air temperatures were higher above white TPO roofs versus above black EPDM roofs at a height of 30 cm, with differences negligible above that height. Lindsey et al. (2006) found that metallic conduits within 2.5 cm of a roof surface were hotter above a black roof, but above that height were hotter above a white roof.

The present study builds on previous work by the authors (Grant, Black, & Werre, 2017) and seeks to answer the following questions:

(1) What is the effect of roof membrane reflectivity on air temperatures at various heights above the roof surface?

(2) What is the effect of roof membrane reflectivity on temperatures of electrical metallic tubing (EMT) at various heights above the roof surface?

(3) What is the effect of roof membrane reflectivity on temperatures of opaque wall surfaces adjacent and perpendicular to the roof surface?

(4) What is the effect of roof membrane reflectivity on exterior and interior temperatures of glazed wall surfaces adjacent and perpendicular to the roof surface?

Methodology

An experimental study was conducted atop the roof of the Virginia-Maryland College of Veterinary Medicine in Blacksburg, Virginia, adjacent to a west-southwest-facing opaque wall and a south-southwest-facing glazed wall. 12m by 6m overlays of TPO and EPDM were adhered to the existing EPDM membrane near the opaque wall, and 6m by 6m overlays were installed next to the glazed wall. Beginning on September 30, 2015, 102 Onset S-TMB-M006 smart temperature sensors along with a weather station were installed in the study area (Figure 1). Temperature sensors were positioned inside specialized M-RSA radiation shields in the air above the membranes, and affixed to conduits above the membranes at 8, 14, 23 and 86 cm at locations marked T1. Sensors were also adhered to precast concrete wall panels and double-glazed aluminum-framed windows at 56, 86, 132 and 162 cm above the roof at locations marked T2. Three replications of temperature measurements were taken at all study locations.

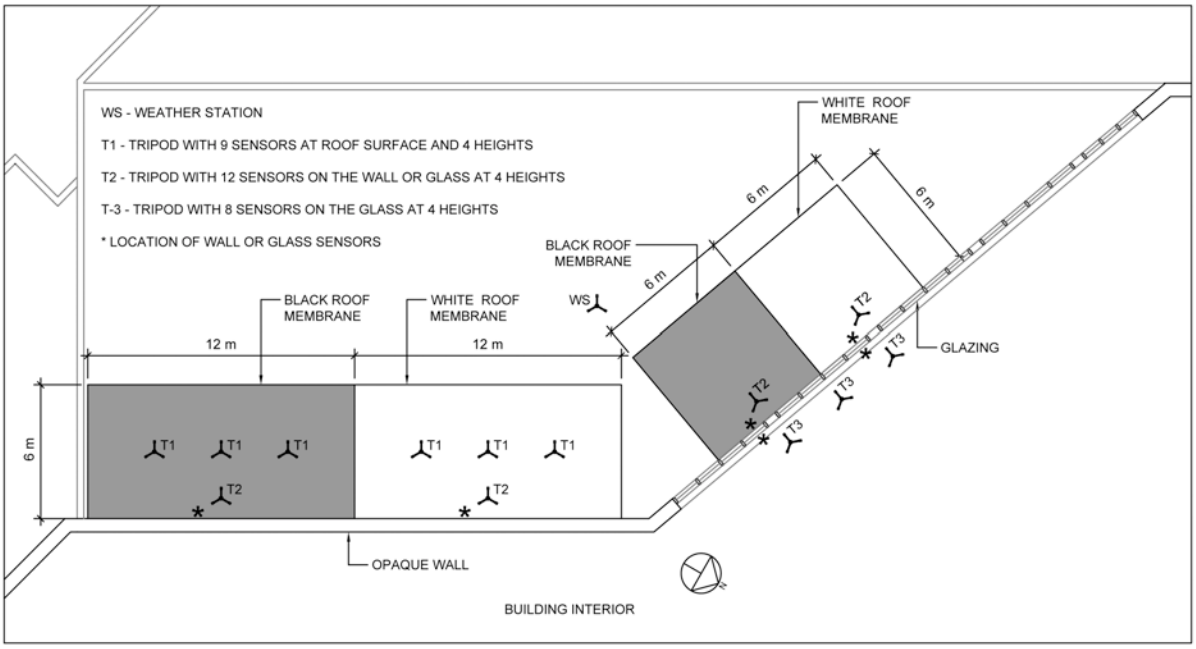

Figure 1. Diagram of experimental setup

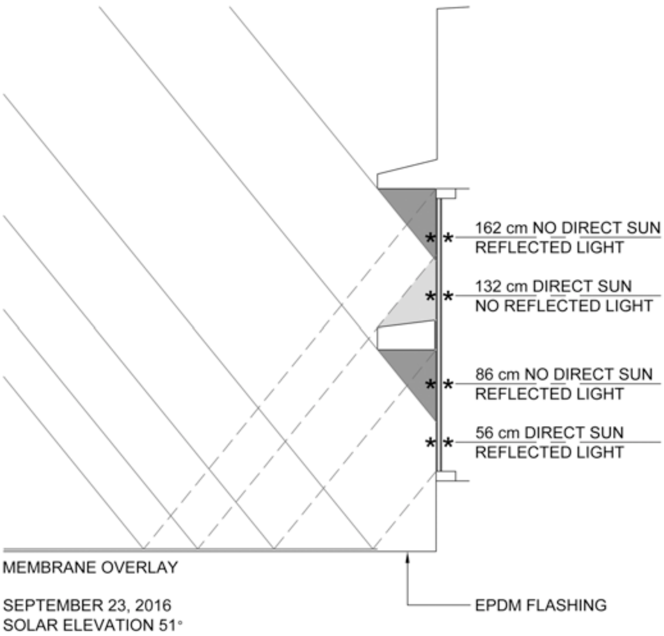

Figure 2. Geometry of direct and reflected sunlight at glazed wall sensors on September 23, 2016 at 14:00 EDT. The solar elevation on October 21 was 43 degrees.

On July 7, 2016, additional sensors were placed on the inside of the glazing to determine the effects of the two types of adjacent roof surface on glass temperatures without the potential interference of the wind. These sensors were linked to three remote data loggers shown at locations marked T3. Because the glass is protected from both direct sun and reflected light off the adjacent roof by two solar shades, and because high-angle sunlight bounces off the existing EPDM flashing rather than the membrane overlays, temperature measurements were only collected on study dates between the autumnal and vernal equinoxes when solar elevations were sufficiently low (Figure 2). Data collected from the sensors at 132 cm were not used as a solar shade blocks reflected light at this location.

Results and Discussion

Data were collected on selected dates while all mechanical equipment in the area was shut down, avoiding the potential interference of an exhaust vent discharging onto the roof near the study area. Thirty-minute temperature averages were centered on the moment when the solar azimuth was perpendicular to the opaque wall or the glazed wall as appropriate.

Table 1. Weather characteristics at times of data analysis for air, EMT and opaque wall surface temperatures, and glazing surface temperatures (highlighted in gray)

Date	Time Range	Avg. Ambient Temperature (°C)	Avg. Relative Humidity (%)	Avg. Solar Radiation (W/m^2)	Avg. Wind Speed (m/s)	Solar Azimuth (°)	Solar Elevation (°)
September 23, 2016	16:30-17:00 EDT	30	40	418	0.34	245	28
October 12, 2016	16:30-17:00 EDT	22	47	338	0.12	240	22
September 23, 2016	13:45-14:15 EDT	29	45	777	0.37	198	51
October 12, 2016	13:45-14:15 EDT	19	53	700	0.12	198	43

Statistical analysis

Normal probability plots showed that temperatures (the primary outcome) followed an approximately normal distribution. Subsequently data were summarized as means or least squares means. To test the effects of type of roof membrane at different heights in the air, at the EMT, on the opaque wall or on the glazed wall, data were analysed using mixed model analysis of variance. Type of roof and height were the fixed effects in the model for each set of analyses. Sensor within type of roof was specified as the random effect. Statistical significance was set to $P < 0.05$. All analyses were performed using SAS version 9.4 (Cary, NC, USA).

Results from September 23, 2016 are shown in Figures 3 through 6. Outcomes from October 12, 2016 are not shown due to space constraints, but will be mentioned in conjunction with the September results. Throughout, the discussion is limited to statistically significant results and rounded to the closest degree. Air temperature measurements on September 23 (Figure 3) were 1°C warmer above the EPDM membrane than the TPO at heights of 8 and 14 cm, but 1°C warmer above the TPO than the EPDM at 86 cm. On October 12, the air above the EPDM was 1°C warmer at 8 cm.

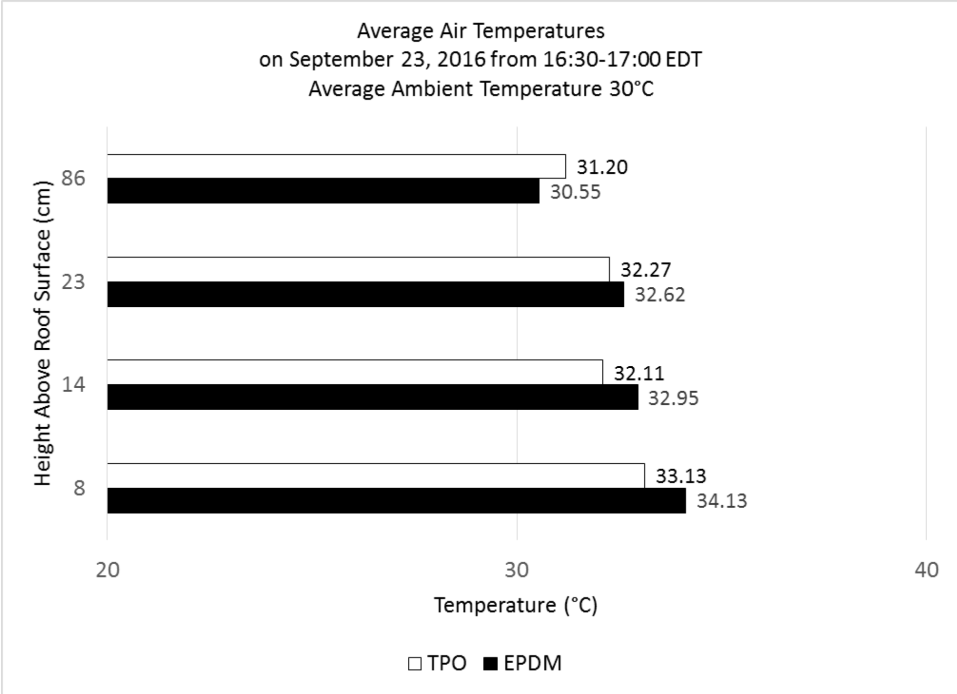

Figure 3. Average air temperatures on September 23, 2016. Differences are statistically significant at 8, 14, and 86 cm.

On September 23, the EMT was an average of 2°C warmer above the TPO surface at 8 cm (Figure 4). No significant differences were observed on October 12 at the EMT.

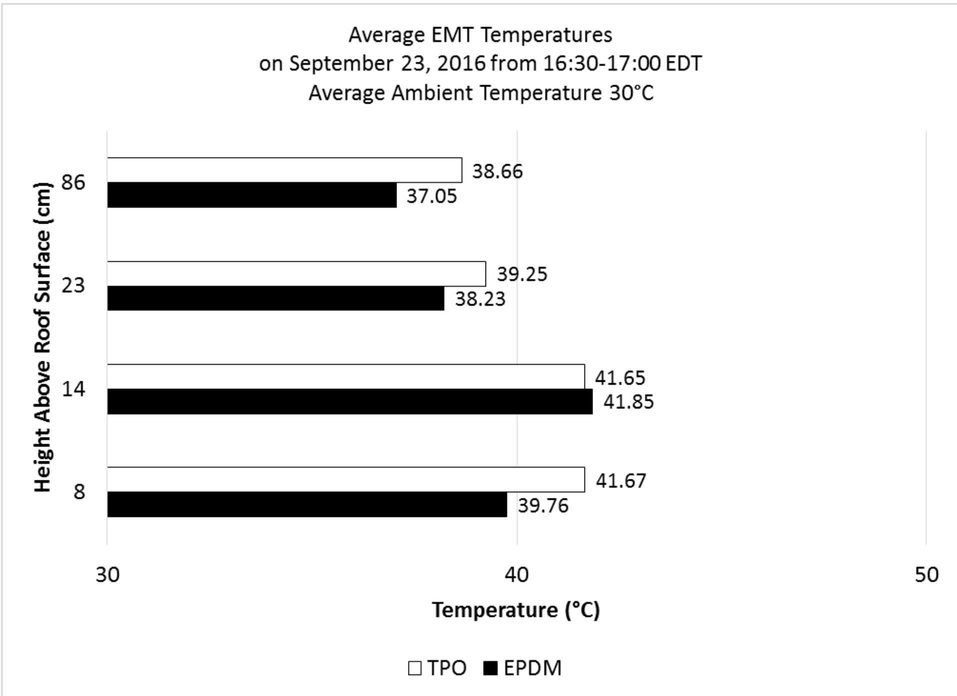

Figure 4. Average EMT temperatures on September 23, 2016. The difference is statistically significant at 8 cm.

On September 23, the opaque wall was 3°C warmer adjacent to the TPO surface than to the EPDM surface at 132 cm, and 4°C warmer at 162 cm (Figure 5). On October 12, the TPO was again warmer by 3°C at 132 cm, and by 5°C at 162 cm.

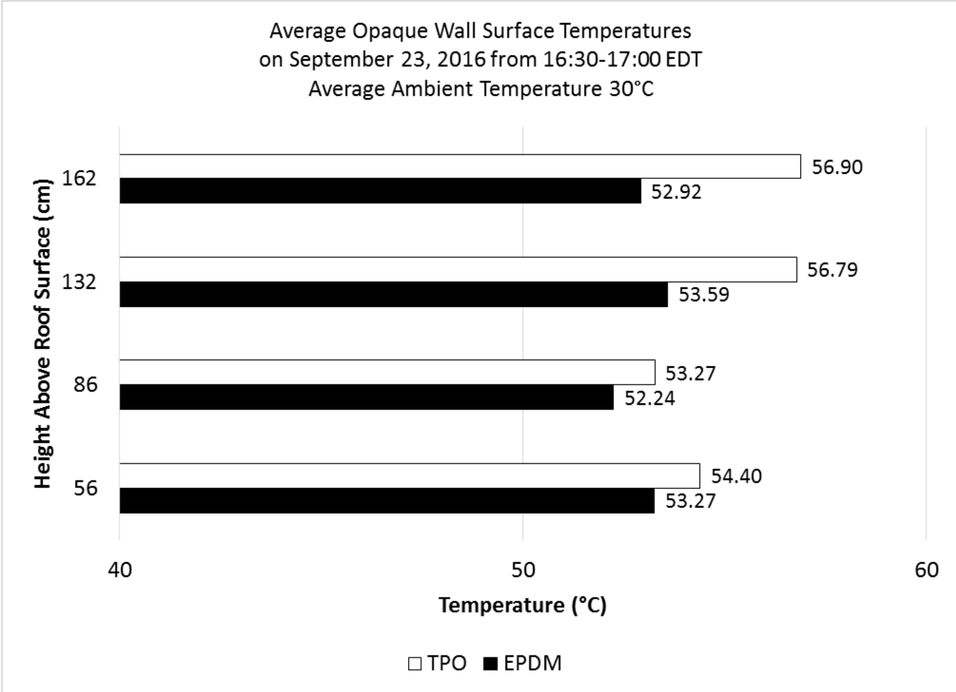

Figure 5. Average opaque wall surface temperatures on September 23, 2016. Differences are statistically significant at 132 and 162 cm.

Results at the glazing were mixed on both study days, both inside and outside the glass, with no differences deemed statistically significant on either day (Figure 6).

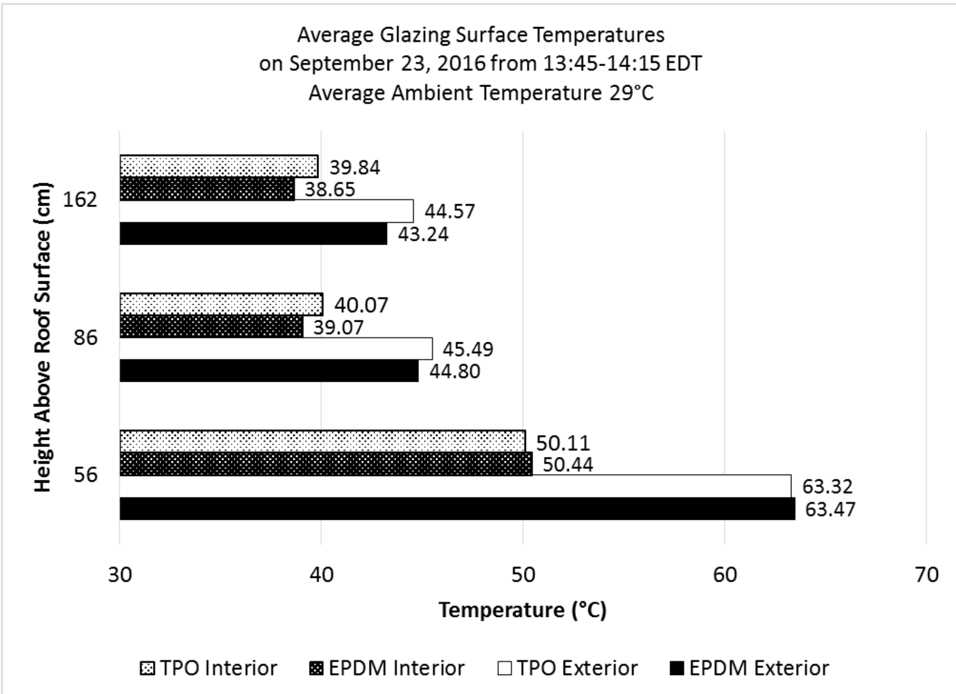

Figure 6. Average glazing surface temperatures on September 23, 2016. Differences are not statistically significant.

Conclusions

Proceeding in the order of the four research questions, conclusions are drawn with respect to the data collected on September 23 and October 12, 2016, and related to previous findings from data collected on March 8, May 24 and August 12, 2016 (Grant, Black, & Werre, 2017).

In September, air temperatures were 1°C warmer above the EPDM roof at 8 cm and 14 cm, while in October air temperatures were 1°C warmer above the EPDM roof at 8 cm. Similarly, in May and August, air temperatures were 2°C warmer above the EPDM roof at 8 cm and 14 cm. This greater difference may be due to the higher solar elevation angles (63° and 55° in May and August, respectively, versus 28° and 22° in September and October, respectively) and the higher average solar radiation during the spring and summer data collection periods (788 W/m^2 on May 24 and 811 W/m^2 on August 12) versus in the fall (418 W/m^2 on September 23 and 338 W/m^2 on October 12). The present study found that, in September, air above the TPO roof was hotter than that above the EPDM roof by 1°C at 86 cm. No other significant results were found at other heights on any of the four days tested. These findings point to the general conclusion that air above EPDM roofs is slightly warmer than air above TPO roofs in close proximity to the roof surface, but that otherwise, air temperature differences between the two are essentially negligible.

EMT temperatures were an average of 2°C warmer above the TPO surface at 8 cm on September 23. The same temperature differential was previously found at 8, 23 and 86 cm in May and at 8 cm and 86 cm in August. This replication of findings indicates that electrical metallic tubing is likely to be hotter above a TPO membrane than an EPDM membrane, and again, the weaker solar radiation in October may explain the absence of significant temperature differences on that day.

Temperatures at the opaque wall were found to be from 3°C to 5°C higher adjacent to the TPO membrane at 132 and 162 cm in September and October, which generally aligned with findings from May and August. The new data corroborate the previous conclusion that the greater reflectivity of the TPO contributed to greater warming of precast concrete panel walls.

Roof reflectivity did not have a significant effect on adjacent exterior or interior glass temperatures in the present study. On March 8, 2016, when glazing surface temperatures were previously measured at the exterior only, they were 2°C hotter adjacent to the TPO membrane. Solar altitude angles were similar on all three dates (46° in March, 51° in September and 43° in October), as were solar radiation levels (737 W/m^2 on March 8, 777 W/m^2 on September 23, and 700 W/m^2 on October 12). The wind was calm on all three dates, and the average air temperature on March 8 was 22°C, which was similar to the temperature on October 12 and much cooler than on September 23 (Table 1). The average relative humidity was only 29% on March 8 while it was 45% in September and 53% in October. While the interaction of weather variables with temperature outcomes was not statistically examined in this study, these interactions may help to explain the differing results. Additionally, while it was not studied quantitatively, it is interesting to note that the average temperature differences between roof membrane treatments found at sensors both outside and inside the glass were qualitatively similar (Figure 6), though exterior temperatures were higher at all heights, and all temperatures were highest at 56 cm where sensors were in the direct sun. These observations suggest that the exterior sensors, at least during calm wind conditions, served as adequate predictors of interior temperature differentials.

Outcomes of the study as a whole point to the need to consider the effects of light bounced off of low-slope reflective roofs toward adjacent building components, namely electrical and mechanical equipment and perpendicular vertical building surfaces. For the most part, these effects are strongest in the months when solar radiation and solar altitude are at their peaks, and the impacts of unwanted heat energy are most problematic. Architects and roof designers need to be cognizant of the influence of their roofing system selections on the environments surrounding roofs. Doing so is necessary to protect the interests of building owners and their neighbors, and, more broadly, to minimize negative impacts on climate at both the micro and macro scales.

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Design to Thrive

Assessing the occurrence of summertime overheating in occupied and unoccupied low energy homes

Rajat Gupta[1], Matt Gregg[1] and Adorkor Bruce-Konuah[1]

[1] Low Carbon Building Group, School of Architecture, Oxford Brookes University, Oxford, UK
email: rgupta@brookes.ac.uk, mgregg@brookes.ac.uk, nbruce-konuah@brookes.ac.uk

Abstract: This paper presents an empirical study to assess the occurrence and possible causes of summertime overheating in three occupied and two unoccupied low energy dwellings in the UK. All five dwellings are identical in terms of construction and location, but have different occupancy profiles and household compositions in the three occupied dwellings. An interdisciplinary approach is adopted, drawing from building science and social science methods, including monitoring of interior environmental conditions, thermal comfort diaries and interviews with residents. Temperature data from bedrooms and living rooms from the case study homes were analysed for overheating using both static and adaptive thermal comfort analyses methods. The findings suggest that summertime overheating is prevalent across both occupied and unoccupied case study dwellings, although overheating assessment using static criteria found a much higher proportion of the rooms to be overheated than the adaptive criteria. In the dwellings a common finding was that bedrooms were found to be more prone to overheating than living rooms. Since it is likely that methods used to assess overheating will be incorporated into regulations in future affecting the design of housing, it is necessary to deploy passive design strategies to prevent the overheating risk in low energy homes.

Keywords: overheating, code for sustainable homes, post occupancy evaluation, adaptive thermal comfort

Introduction

Despite the relatively mild climate of the UK, concern has increased about summertime temperatures in air-tight low energy houses due to the effects of high temperatures on occupant health (Armstrong et al., 2010). There is in fact growing evidence of overheating in homes, particularly in newer homes built to satisfy more demanding standards of energy efficiency (ZCH, no date). The term overheating is used to describe when temperatures make building occupants uncomfortable or heat stressed. With consecutive days of hot weather (including warmer than average nights), internal temperatures in some homes, particularly newer efficient homes, can start to exceed external temperatures and may no longer provide protection from the heat. These conditions can cause discomfort and heat-related effects on health (Armstrong et al., 2010, Hajat et al., 2014).

Overheating can occur in homes as a result of a number of causes acting alone or in combination. These can include heat gain from high external temperatures, direct solar gain on the exterior surface or penetrating glazing, and internal heat gains. Home characteristics such as dark surface materials, rooms in the roof, skylights, inability to ventilate due to location, predominately dark hard surface surroundings, single aspect flats on upper floors, and orientation that allows late solar gain in windows can all contribute to overheating (Gupta and Gregg, 2012). For more vulnerable occupants, such as infants, the elderly or sick, the risk of severe heat stress, including potentially fatal heat stroke, is greater. To make matters worse, these people are typically at home for most of the day and exposed to peak day temperatures, unlike those who go out to work. The cause of overheating is complex and not a simple measure of maximum temperatures; therefore, long continuous periods of above-average indoor temperatures in homes are used to evaluate this condition.

Much research has set out to establish the risk of overheating by simulating the current and future risk in older dwellings (Gupta and Gregg, 2013) and in newer dwellings (McLeod et al., 2013). A number of studies have also demonstrated present-day monitored overheating or summer 'discomfort' in existing dwellings and newly built dwellings (Sameni et al., 2015) in the UK and abroad, in Denmark (Larsen and Jensen, 2011), Sweden (Ruud et al., 2005) and Estonia (Maivel et al., 2015). Within these studies the propensity to overheat is much greater in newer dwellings, e.g. passivhaus designed dwellings, and particularly in flats. It is important to note that overheating is defined slightly differently from region to region, however, there is roughly an agreement that surpassing hours at 26-27^{o}C is problematic.

To contribute to this body of knowledge, the objective of this study is to investigate the extent of overheating in both occupied and unoccupied dwellings in York, England. The homes are newly-built within the past few years and are built to the highest energy efficiency levels under the UK standards current at the time, i.e. Code for Sustainable Homes Level 4. An interdisciplinary approach is adopted, drawing from building science and social science methods, including monitoring of temperature and relative humidity in the living room and principal bedrooms over August and September 2016, dwelling surveys, thermal comfort diaries and interviews with residents.

Methodology

The study involved five dwellings, three occupied dwellings (H1 – H3) and two unoccupied dwellings which are show-homes for the development (SH1 & SH2). All five dwellings are identical in terms of construction and location, but have different orientations and the three occupied dwellings have different occupancy compositions. Table 1 lists some dwelling characteristics for the homes.

Table 1. Summary of characteristics of the case study dwellings
(N/A indicates where some data were unavailable; EPC = Energy Performance Certificate)

	H1	H2	H3	SH1	SH2
Built form	Detached	Mid-terrace	Semi-detached	Detached	Mid-terrace
Front orientation	East (slightly N)	North (slightly E)	South (slightly W)	East (slightly N)	South (slightly E)
Total floor area	84 m^2	118 m^2	93 m^2	N/A	N/A
Occupants	1 adult	2 adults, 1 child	2 adults, 2 children	No occupants	No occupants
EPC rating	B (81)	B (85)	B (83)	B	B
Air permeability	3.8 $m^3/h.m^2$	3.7 $m^3/h.m^2$	3.8 $m^3/h.m^2$	N/A	N/A

Overheating assessment methods

For the overheating assessment, two methodologies were used. These are the *static method* and the *adaptive method*. The static method defines overheating as when in living areas, 1% of occupied hours is >28°C and in bedrooms, 1% of occupied hours >26°C

(Humphreys and Nicol, 2006). The adaptive method is a dynamic threshold based on changes in external temperature which also includes levels of occupant sensitivity. The adaptive method defines overheating as when two of the following three criteria are failed: 1) hours of exceedance, 2) daily weighted exceedance, and 3) upper limit temperature (Nicol and Spires, 2013).

Quantitative data collection and assumptions

The evaluation of overheating risk employed internal and external temperature readings on a quarter-hourly basis using internal and external Onset HOBOs and occupancy hours of the monitored spaces. The monitoring of living rooms and bedrooms of all dwellings took place from August 11th – November 24th 2016. This provided partial data on overheating for the summer; specifically, from August 11th – September 30th. In addition to interior spaces, two exterior data loggers were placed outside of H1 and SH1. The exterior (micro-climate) data were found to follow the same pattern; however, a mean was taken between the two loggers to represent the external condition. Actual occupancy details were not collected, however, assumed occupancy schedules are applied for analysis. Consistency across all dwellings in this way assists in comparing the unoccupied dwellings with the occupied dwellings. It is likely; however, that because there is a very young child living in H2, the occupancy varies from this general assumption. The occupancy hours used were 6:00 – 8:00 and 18:00 – 22:00 for the living rooms and 22:00 – 6:00 for the bedrooms.

Qualitative data collection

For H1 & H2, household surveys, interviews and a thermal comfort diary (H2 only) were employed to collect information on occupants' comfort perception, lifestyle, behaviour, use of windows, appliances, etc.

Table 2. Interview summary

	H1	H2
Comfort in summer	Summer is comfortable	Hot throughout the house, main bedroom most uncomfortable
Most occupied space	Living room	No comment
Method to keep cool	Open windows at about 25°C (uses digital thermostat to observe interior temperature), shorts and t-shirt, cool drinks	Open windows and trickle vents to cool down the space
Window behaviour	Open windows in all rooms daily when home / do not leave them open when away from home, window trickle vents left open in summer	Windows opened whenever necessary in all rooms; however, living room and second bedroom windows are closed overnight
Ventilation or fans	No ventilation units or fans	No ventilation units or fans
Interior doors	Always left open	Always left open
Blinds	Occasionally used	Occasionally used

Results

Table 3 shows the overall findings with relation to the overheating in the dwellings. All dwellings have some level of overheating according to the static method; however, there were no temperature readings >28°C. No dwellings overheat according to the adaptive method (which requires two criteria to fail). It is important to consider that the adaptive method has been developed in and for non-domestic buildings, though this does not explain its lower sensitivity. However, it is useful to evaluate as it considers more variables and theorises an adaptive response from occupants. Only some bedrooms overheated during (expected) occupied hours of the bedrooms. In the occupied dwellings, only the second bedroom overheats in all three cases. In the show-homes both bedrooms overheat. It is theorised that bedroom 1 in the occupied dwellings do not overheat because the adult(s) (prime occupant) control the windows to alleviate overheating in the space. The antithesis of this is potentially why only the second bedrooms overheat. As the show-homes are not occupied during bedroom occupancy hours, windows are not open; this is why overheating occurs in both bedrooms of two of the show-homes.

Table 3. Overheating results from 11 August – 30 September
(N = north, E = east, W = west, S = south, +sky = skylight, OH = overheating)

	Room	Window orientation	Static method	Adaptive method (failed)	Occupied hours between 26 – 28°C
H1	Living room	NE / SW	0%	-	0%
	Bedroom 1	NE	0%	-	0%
	Bedroom 2	**SW**	**4% - OH**	-	**7%**
H2	Living room	S	0%	-	**3%**
	Bedroom 1	N / S +sky	0%	-	0%
	Bedroom 2	**S**	**2% - OH**	-	**4%**
H3	Living room	SW / NE	0%	-	0%
	Bedroom 1	NE	0%	-	**1%**
	Bedroom 2	**SW**	**3% - OH**	-	**4%**
SH1	Living room	E / W	0%	-	0%
	Bedroom 1	**W**	**6% - OH**	Criterion 2	**8%**
	Bedroom 2	**E**	**14% - OH**	Criterion 2	**13%**
SH2	Living room	N	0%	-	0%
	Bedroom 1	**S / N +sky**	**2% - OH**	-	**7%**
	Bedroom 2	**S**	**4% - OH**	-	**2%**

The H1 occupant considers the summer conditions in the house comfortable and overheating results reflect this. As there is only one occupant in H1, it is probable that the occupant does not use the 2nd bedroom or experience the overheating in that space. In contrast, the responses from H2 show that the occupant finds it hot throughout the house with the main bedroom, as most uncomfortable. Interestingly, it is the main bedroom which has the highest proportion of lower temperatures than the other rooms; this however, could be the perception before opening windows to ventilate, wherein the measurements show the impact of opened windows. Survey responses may also indicate the thermal comfort opinion of the occupants between these two homes, whereas: H1 begins the heating season in October with a heating set-point of 21-22°C and H2 begins the heating season in November with a heating set-point of 18°C. These findings may suggest that the occupant of H2 has a lower tolerance for higher temperatures.

Thermal comfort diary assessment

Thermal comfort diaries were only completed by H2. The results for the actual mean vote (AMV) and predicted mean vote (PMV) corroborate the previous assumption, that the occupant of H2 may be more sensitive to warmer temperatures than other occupants. This can be seen in figure 1, where the AMV is essentially a two point shift above the PMV.

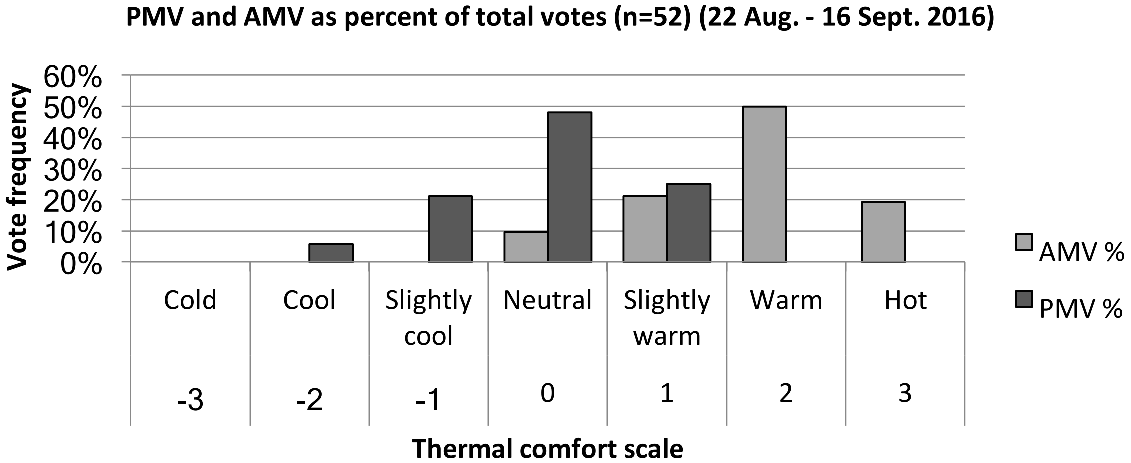

Figure 1. PMV and AMV percentage votes.

Overheating factors

Occupied vs. unoccupied

Neither dwelling type overheats in an overall sense more than the other purely due to occupancy status. This can be seen by comparing SH2 to the occupied dwellings; however, the lack of active ventilating in the SHs is apparent in the bedrooms. Figure 2 focuses on the evening hours to further investigate the difference between the occupied and unoccupied houses. The intent is to observe the dwellings during the 7pm – 7am period, when it is theorised that the show-homes are sealed and unoccupied. As expected, the show homes demonstrate steadier temperature readings due to lack of occupants. A difference between occupied and unoccupied dwellings is difficult to see in the living room, as most dwellings appear to retain similar temperatures and patterns of change during the periods of focus. The bedrooms during this period indicate a different pattern. The occupied dwellings for the most part, appear to be ventilating at night as the temperatures are 1-3°C lower than the show-homes. The tendency for H2 is to exhibit sharp peaks of overheating in response to high temperatures. These sharp peaks were most likely not experienced in the bedrooms as they tend to happen during mid-day when external temperatures were highest and bedrooms are not occupied. According to the interviews, though windows were often used to cool down spaces, windows were not left open when rooms (or the dwelling) were not occupied. SH1, in contrast, retained a steady higher internal temperature though without the sharpness of the peaks. The consistency of the higher temperatures is likely due to the lack of window opening in the show home, particularly in the evening. The remaining dwellings whether occupied or not, appeared to demonstrate a lower level of sensitivity to the external temperature spikes. This may be due to orientation or different space management. Though the dwellings demonstrated the same responsive patterns, overall the temperatures for all dwellings were roughly 2°C cooler in the living rooms than in the bedrooms.

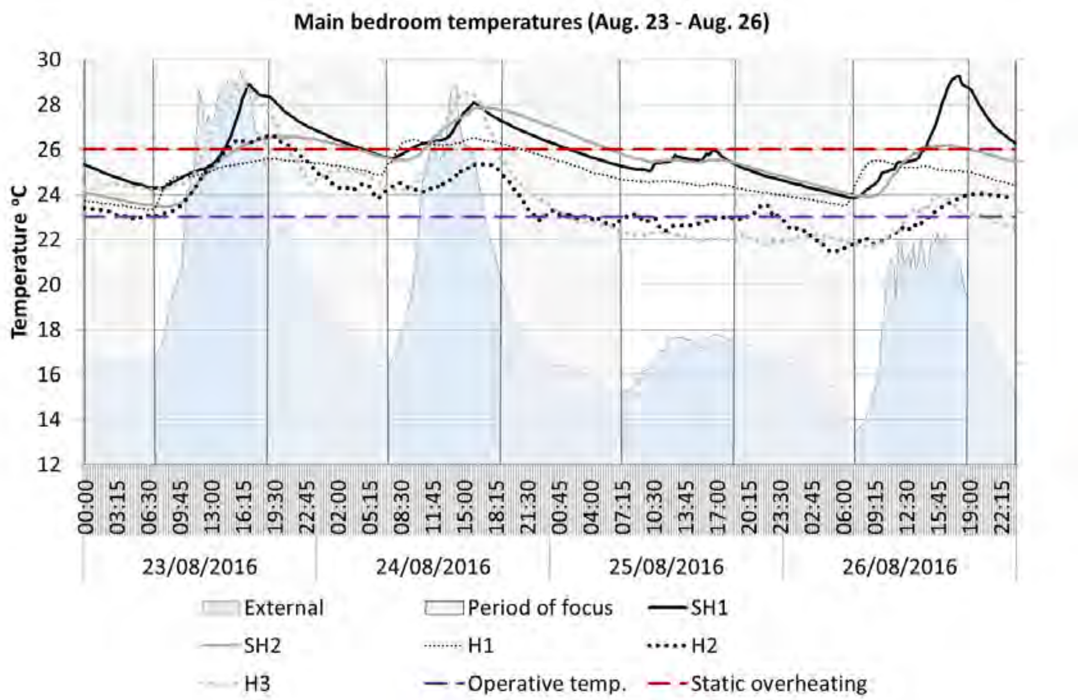

Figure 2. Occupied vs. unoccupied dwelling temperatures in bedroom 1

Orientation

Considering the orientation of the rooms, table 3 demonstrates the following. There is greater tendency to overheat in south, west and east facing rooms. Excluding the influence of occupants, it might be concluded that dwellings with E/W orientation (e.g. SH1) have a much greater tendency to overheat than N/S.

Different occupancy hours

Those most vulnerable to overheating, such as the elderly or sick, are more likely to occupy their homes during daytime, when the heat is most intense. Whereas in the preceding analysis, occupied hours are assumed to be generalized, the following explores a scenario where the dwellings are occupied full time. Figure 3 shows a side-by-side comparison of total hours and occupied hours (the hours assumed in the methodology above).

At first, it is expected that in most cases, total hours will show greater overheating than the occupied hours due to the higher daytime temperature and direct solar gain. This does appear to be true for a majority of the spaces, especially the 2nd bedroom in H2 and the 1st bedroom in the SH1. Interestingly however, bedroom 2 in H3 has a higher level of overheating during the generalized occupied hours as opposed to the total hours. The fact that this space is southwest orientated could help to explain this; that is, most of the overheating occurs in the late afternoon / evening hours, as the sun sets, closer to occupancy time of the bedroom. Also in reality, actual presence of people (H3 has most occupants) in the space can add to the internal heat gain of the room, thereby, increasing the actual measured temperature of the space during assumed occupancy hours.

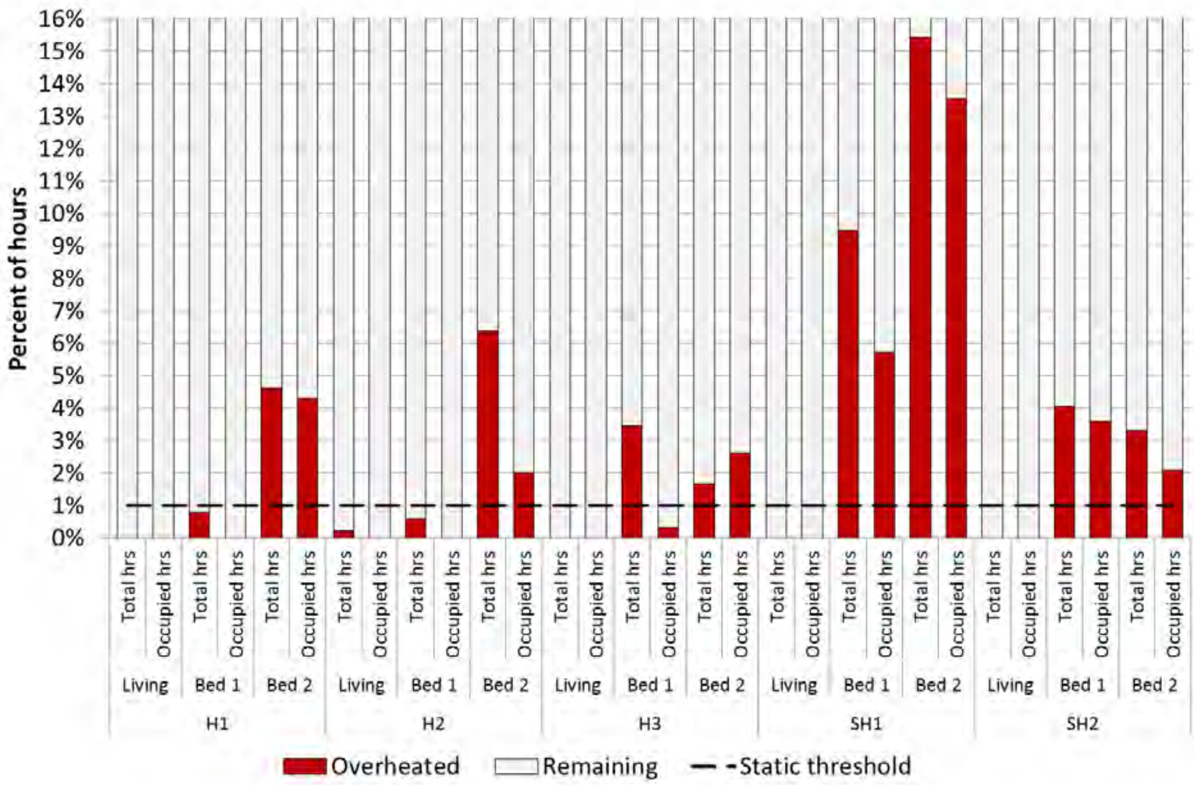

Figure **3**. Percent of hours overheated for all rooms

Concluding discussion

This study is based on data collected between August and November 2016 in five dwellings located in a new low-energy development in York, England. Analysis of the results showed that in general, overheating is prevalent in both occupied and un-occupied homes. Bedrooms, particularly those facing south, east or west, more specifically the upper levels of the dwellings, are more prone to overheating than living rooms. The living rooms in contrast, are large, open, and can be cross-ventilated and potentially well managed to avoid the risk of overheating. One contributing attribute is the open plan where the living room (or 'lounge') is shared with other spaces. In addition, in the two dwellings interviewed, the normal practice was to always leave the door open from the living space to the hall and stairs. This allows heat to move more freely and to not remain trapped in the living area. The movement of heat into the upper levels may also contribute to the higher propensity of overheating in the upper level rooms. It is also expected that this openness of all doors is prominent in the show-homes to give visitors a welcoming feeling.

SH1, an unoccupied dwelling, exhibited significant overheating results. The presence of occupancy appears to most obviously affect the overheating potential in bedrooms, where window ventilation is essential to alleviating or reducing overheating potential. No ventilation or fans were found among the interviewed occupants; however, the frequent use of windows in these dwellings has helped mitigate overheating to some degree in the monitored spaces. In most cases, where rooms are occupied all day, the overheating potential is higher. One exception to this is in southwest orientated bedrooms. These bedrooms tend to have overheating hours concentrated in the evening and at night.

It important to note that design has a heavy influence on overheating and given the findings, adaptive measures would definitely have their place in current new-build. Passive design strategies such as designed in shading and light coloured surfaces, etc., evaluated elsewhere (Porritt et al., 2012, Gupta and Gregg, 2013, McLeod et al., 2013), continually prove effective when tested in the literature. It is however, also vital to engage with occupant about managing heat during hot weather. Occupant behaviour is highly important when affecting the level of overheating. This is apparent in the assessment of both unoccupied homes and in second bedrooms of occupied homes where there is less or no occupant use of windows. Though SH1's temperature profile follows that of SH2, the internal temperatures are consistently 2^{o}C higher in the bedrooms in the summer. The greater level of overheating in SH1 cannot be explained without further investigation into management of the space.

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A new empirical model incorporating spatial interpolation of meteorological data for the prediction of overheating risks in UK dwellings

Matej Gustin[1, 2], Argyris Oraiopoulos[1, 2], Robert S. McLeod[1, 2] and Kevin J. Lomas[1, 2]

[1] Building Energy Research Group (BERG), School of Civil and Building Engineering, Loughborough University, Loughborough, UK;
[2]London – Loughborough Centre for Doctoral Training in Energy Demand (LoLo CDT), Loughborough University, Loughborough, UK, a.oraiopoulos@lboro.ac.uk

Abstract: Heat-related morbidity and mortality is anticipated to increase as climatic change induced overheating become increasingly common. The development of building-specific predictive models has the potential to alert occupants and emergency services to the severity of impending risks. This research aims to evaluate the implementation of a newly developed time series model for overheating prediction. Since risk forecasting is contingent upon the accuracy of the model at different future time steps, the sensitivity of model outputs to the uncertainty in the data inputs needs to be understood. Internal and external climatic variables were monitored in an unoccupied domestic dwelling in order to evaluate the empirical model's predictive accuracy. The uncertainty related to the proximity of external weather stations was evaluated using data taken from four nearby weather stations and further bespoke data sets derived by interpolation. The results confirmed the overall accuracy of the newly developed time series predictive model, whilst highlighting the benefits of climatic data interpolation in reducing predictive uncertainties. The empirically derived modelling approach showed a low variance to the actual temperature evolution over a seven-day predictive period, pointing to its validity as a robust model for the prediction of future overheating risks.

Keywords: Overheating, Time Series Analysis Method, Uncertainty, Meteorological data, Spatial interpolation

Introduction

Context

Time series data, spanning more than a century, illustrates that the most populous regions on Earth are experiencing progressively hotter annual temperatures (NASA & GISS, 2017). Warmer than average summers coupled with an increased frequency of extreme heat wave events (Jenkins et al., 2008) pose obvious risk factors in relation to overheating in the built environment. Events such as the 2003 heat wave, which is reported to have resulted in over 2000 heat-related deaths in the UK, are predicted to become increasingly common (Armstrong et al., 2011; Hajat et al., 2006; Rooney et al., 1998; Wright et al., 2005).

Active cooling systems remain relatively uncommon in UK homes but their uptake is projected to increase rapidly (Pathan et al., 2008). O'Neill et al. (2005) point out that unless extensively subsidised however, the ownership of cooling systems is likely to reflect socioeconomic inequalities thereby rendering disadvantaged households more vulnerable. Furthermore widespread power outages in North America and Australia during heat waves have highlighted the risks associated with reliance upon active cooling systems at times of grid overload (Ostro et al., 2010).

Despite strong epidemiological correlations between elevated external temperatures and increased risks of heat-related morbidity and mortality (Armstrong et al., 2011; Vardoulakis & Heaviside, 2012) relatively little is known about internal temperature evolution under these conditions. Real-time predictive overheating models are needed in order to understand when critical thresholds are likely to be breached in specific buildings and to warn occupants and facility managers when health-endangering environmental conditions are anticipated to occur.

Background – the development of time series models and indoor temperature prediction

Studies related to overheating in dwellings, conducted in recent years, can be broadly categorised as: those that involved measuring internal temperatures in order to identify and quantify the risk of overheating (Beizaee et al., 2013; McLeod and Swainson, 2017; Pathan et al., 2017), those that involved dynamic thermal simulation modelling to assess the current and future risk of overheating in dwellings (McLeod et at., 2013; Mavrogianni et al., 2012); and those that have used empirical data to construct predictive models in order to assess overheating both spatially and temporally (Mlakar & Strancar, 2011; Mirzaei et al., 2012). Modelling methods that make use of measurements to explain the variation in the data present advantages over other modelling methods that typically entail large numbers of assumptions and thereby elevate the level of uncertainty in the results. The Time Series Analysis Method (TSAM) has been successfully used in diverse fields such as economics, geophysics, control engineering and meteorology to describe, explain, predict and control processes (Chatfield, 1996). Here the descriptive TSAM is applied to room temperature data. The advantage of TSAM over other black box approaches (such as artificial neural networks, autoregressive models, multiple linear regression models, distributed lag models, transfer functions etc.) is that it is an exploratory technique that allows a clear understanding of the causality of internal temperatures.

Methodology

An empirical TSAM model was used to predict the hourly internal temperature evolution in the test house, in relation to different sources of meteorological data. The data measured on-site were compared with the meteorological data and the modelling predictions in order to assess the effects of the proximity of weather stations and interpolation of weather data on the models' predictive accuracy.

Time series model

This paper utilises a newly developed Internal Trend and Cyclical Component (ITCC) Model, which is based on the descriptive TSAM approach. The principle aim of the descriptive TSAM is to decompose the variation in the series into individual components (Trend, Cyclical variation) that can be described and modelled independently (Fleming & Nellis, 1994). The definition of these components is specific to the dataset used in the analysis. In this work, the components *trend* and *cyclical variation* are defined in relation to the internal air temperature profiles in homes. The *trend* represents the changes in the series from day to day over the (52 days) monitoring period which encompasses the daily variation. Whilst the *cyclical variation* encompasses the diurnal fluctuations of internal temperatures (the variation within a 24h period). These concepts have their origins in the formative work of Chatfield (Chatfield, 1996) and Kendal & Ord (1990).

The detailed methodology describing the ITCC model can be found in Oraiopoulos et al. (2017). The ITCC model is the result of joining the *trend* and the *cyclical* component models together and is given below:

$$\boldsymbol{\theta'_{in,t} = i + g \times \left[(1-\alpha) \times \left(\overline{\theta}_{ex,d} + \alpha\,\overline{\theta}_{ex,d-1} + .. + \alpha^{m}\,\overline{\theta}_{ex,d-m}\right)\right] + A \times C_{ex,\varphi_e} + B \times C_{s,\varphi_s} - \gamma}$$

Where:

$\theta'_{in,t}$	hourly modelled internal air temperature
i	y-axis intercept of the line of best fit for the correlation between the daily mean internal temperature and the exponentially weighted moving average of the daily means external air temperatures
g	gradient of the line of best fit for the correlation between the daily mean internal air temperature and the exponentially weighted moving average of the daily means of the external air temperatures
α	constant between 0.00 and 1.00 (BS EN 15251, 2007)
$\overline{\theta}_{ex,d}$	daily mean of the external air temperature of the current day
$\overline{\theta}_{ex,d-1}$	daily mean of the external air temperature of the previous day
m	total number of previous days used in the formula for the exponentially weighted moving average of the daily mean of the external air temperature
$\overline{\theta}_{ex,d-m}$	daily mean of the external air temperature of the m^{th} previous day
A	numerical coefficient of the cyclical component of the external air temperature
C_{ex,φ_e}	cyclical component of the external air temperature
φ_e	phase of the cyclical component of the external air temperature
B	numerical coefficient of the cyclical component of the solar irradiation
C_{s,φ_s}	cyclical component of the solar irradiation
φ_s	phase of the cyclical component of the solar irradiation
γ	Constant

Test house and empirical data monitoring

The data used in this study was collected from one of two unoccupied, semi-detached test houses located in Mountsorrel, Leicestershire. The experiment was undertaken, and all the data collected, by other researchers as part of a different research project (see acknowledgements), during the summer of 2016. The houses are typical, solid brick walled, family homes dating from the 1910s which have subsequently undergone some refurbishment.

Figure 1. Front elevation (facing S-SE) of the test houses (the left hand house was used in this study).

Weather and environmental data

Internal monitored data

Internal temperature data was collected in the test house from 9 June to 31 July (2016) using a U-type thermistor (accuracy = ±0.2°C) installed in the middle of each room (with an aluminium foil shielding to mitigate radiant heat influences). Logging was carried out at five-minute intervals. During the tests, the windows remained closed, with blinds and trickle vents open. Synthetic occupancy was created, simulating the occupancy profile and appliance usage of an elderly couple (staying at home the whole day): living room (occupied from 08:30 to 23:00) and bedroom (occupied from 23:00 to 07:30).

External weather data – measured on site

External temperatures were monitored on site during the monitoring period (from 9 June to 31 July) using a shielded U-type thermistor (accuracy = ±0.2°C). The sensor was mounted in a shaded location on the North side of the house. The data was logged at the same interval as the internal sensors (five-minute intervals).

External weather data – third party sources

Hourly weather data was gathered from two different sources: Loughborough University (LU) meteorological station and the Centre for Environmental Data Analysis (CEDA, n.d.). Through the CEDA platform, it was possible to access data from the Met Office Integrated Data Archive System (MIDAS): UK Hourly Weather Observation Data. Three MIDAS stations in the proximity of the test house were selected for this study: Sutton Bonington (SB), Coundon Coventry (CC) and Wittering (WIT). The locations of the test house, meteorological stations and their distances from the site are shown on the map in Figure 2.

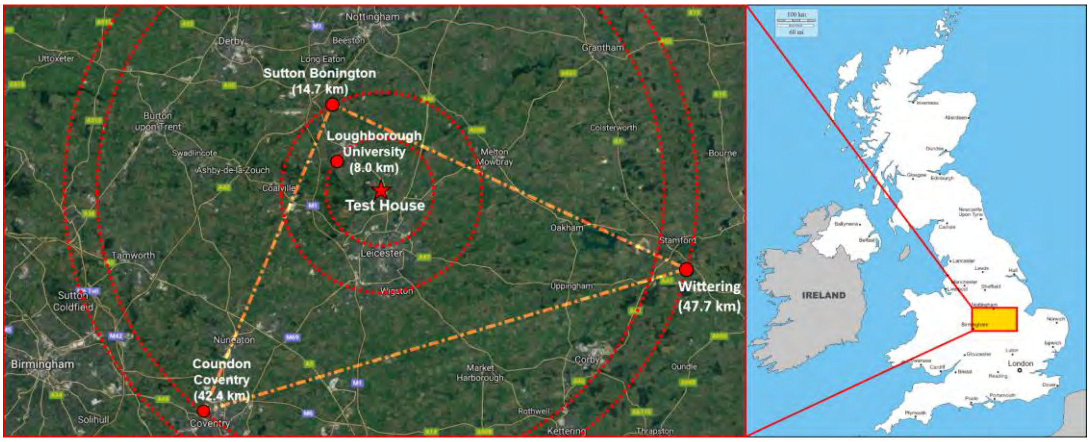

Figure 2. Locations of the test house (star) and meteorological stations (circles) on the map.

External weather data – spatial interpolation

For the spatial interpolation of meteorological data, the method adopted by the Joint Research Centre (JRC) of the European Commission was selected (Voet, Diepen, & Voshaar, 1994). This method was chosen due to its proven reliability and ease of application. Voet et al. (1994) demonstrated that with the averaging of data from optimally sited meteorological stations it is possible to obtain satisfactory results without the use of weighting coefficients or other more complex interpolation methods such as splines, kriging etc. (Franchello, 2005; Hofstra et al., 2008). Although the JRC method was originally developed for interpolating daily meteorological data, in this study the same criteria were adopted for spatial interpolation at an hourly resolution. As suggested by Voet et al. (1994), the optimal number of three weather stations for interpolation was used in this study. The results of interpolation using two meteorological stations are also shown for reference. In this case study, no algorithm was adopted for their selection, but the three closest meteorological stations (triangulating the site) with complete hourly temperature and solar radiation data were chosen. The JRC method foresees that in order to improve the accuracy of the data, the air temperature and has to be corrected to take into account the altitude difference. For every 100m increase in altitude (relative to the site) the temperature was reduced by 0.6°C. To interpolate the data, the corrected station data was then simply averaged.

Overheating

Various criteria have been developed to assess when rooms in a dwelling might be considered as overheated. These include CIBSE static criteria which suggest that the operative temperature (OT) in living rooms should not exceed 28^{o}C for more than 1% of occupied hours in the year, for bedrooms the criterion is 1% of hours over 26^{o}C (CIBSE, 2006). More recently a move towards the use of adaptive overheating thresholds, which vary according to the outdoor temperature, have gained popularity for the assessment of risks in free running (i.e. naturally ventilated) buildings (CIBSE, 2013). In terms of legislation The Health and Safety Rating System (HHSRS) Operating Guidance states that when temperatures exceed 25°C there is a significant increase in the risk of strokes and mortality (HHSRS, 2004). Currently the HHSRS provides the only statutory definition of 'overheating' risks in relation to morbidity and mortality in UK residential properties (McLeod and Swainson, 2017).

Uncertainties analysis

As stated by Hopfe et al (2013), "in the assessment of the performance of a building, it is imprudent to take deterministic values for the input parameters". Moreover, to generate robust predictions, analysis of the measurement uncertainties is required (Buswell, 2013). In order to take measurement uncertainties into account, they were evaluated in accordance with good practice guidance developed by the National Physics Laboratory (Bell, 2001). Using type A (repeated readings) and type B (manufacturer specifications – accuracy) uncertainties for the air temperature measurements were calculated to be ±0.10°C and ±0.12°C respectively, producing a combined standard uncertainty of ±0.15°C. Considering a coverage factor of k=2, the resulting extended standard uncertainty is ±0.30°C, with a confidence interval of 95%.

Model evaluation

The ITCC time series model was trained from 9 June to 16 July, and produced hourly predictions from 17 to 31 July. Since the external air temperature was also monitored on-site, in order to assess the data from the various meteorological stations and the interpolated data, the RMSE between the measured and adopted meteorological data was used as a dispersion metric, as used for example by (Voet et al., 1994). The RMSE was also used to evaluate the errors between predicted and measured internal temperatures in the living room and bedroom. To check the influence that measurement uncertainty has on the results, the RMSE and R^2 were also calculated on the measurement uncertainty limits as an adjunct to using the deterministic values. These values represent the minimum errors and the maximum explanatory power of the model (respectively), which could be achieved when considering the uncertainty in the measurements. Since the model was predicting reliably for the period up to seven days, the errors between the predicted and modelled data were evaluated only for the first week of predictions.

Results and Analysis

Modelling inputs – weather data

As shown in figure 3, when the meteorological data is taken from a single station, the RMSE ranges between 0.93 and 1.32°C, compared to the site values. The RMSE is significant also for the meteorological stations that are very close to the test house. It has to be mentioned that the errors for the MIDAS stations are at certain hours very large, suggesting that the air temperatures are varying more quickly than at the analysed site. This can be easily explained due to the locations of the MIDAS stations, which are usually located in open field, whilst the test house is located in the middle of a small town. However, when the meteorological data is interpolated, the RMSE drops significantly. The best results were obtained using triangulation (interpolation of three meteorological stations), with the RMSE ranging between 0.47 and 0.8°C. This indicates that using triangulation it is possible to improve the input data by 14-64% relative to using a single 'near neighbour' weather station.

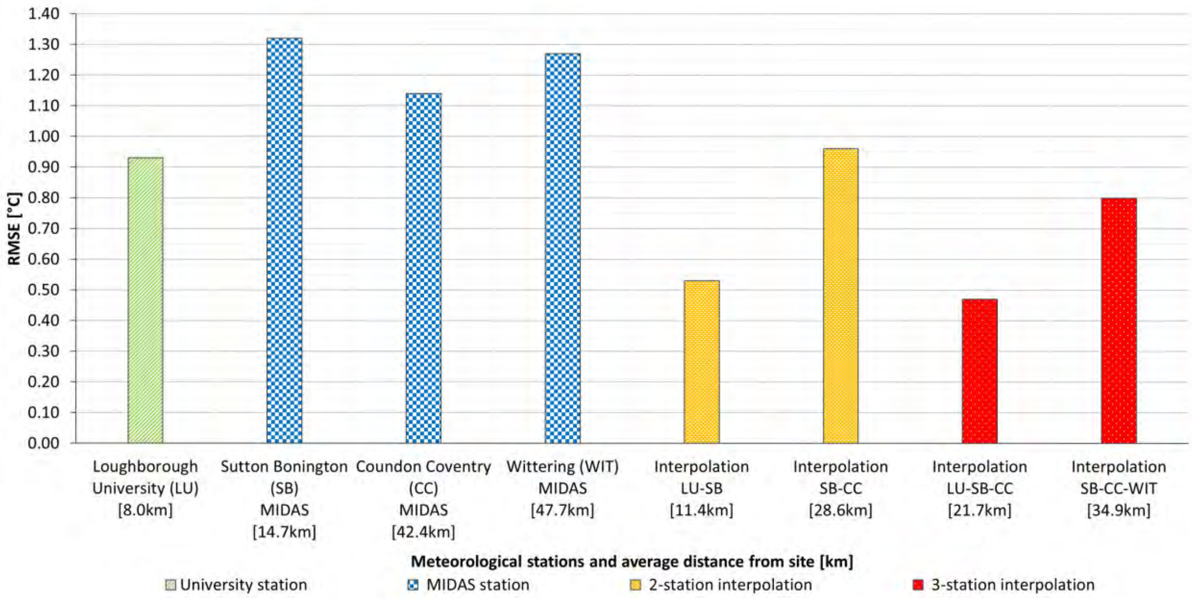

Figure 3. RMSE of the meteorological data against the external temperatures measured on site.

Modelling outputs – hourly predictions

Figure 4 illustrates how the model was trained on 38 days of data to predict the internal temperature evolution for the following 14 days. Due to the increasing inaccuracy of forecasts after day 7, only the first week of predictions was considered in this study.

Overall, the model showed an excellent explanatory power for the first week of predictions for all the meteorological data, with an R2 of 0.876-0.896 for the living room (LR), and 0.943-0.952 for the bedroom (BR). Considering the measurement uncertainty, the explanatory power might be even higher with the potential maximum of 0.937-0.951 (LR) and 0.951-0.960 (BR). As shown in figure 5, taking the data from the closest meteorological station does not guarantee that the most accurate prediction will be achieved. Indeed, in this case, the predicted data showed that while the largest RMSE was obtained from the two closest stations (LU and SB), the lowest RMSE (CC and WIT) was obtained from the two furthest stations. Whilst the interpolation did not show significant reductions in the RMSE of predictions, it is evident that with its use the errors show a greatly reduced variability (Figures 3 and 5), thereby reducing the uncertainty of the data that are used for the model.

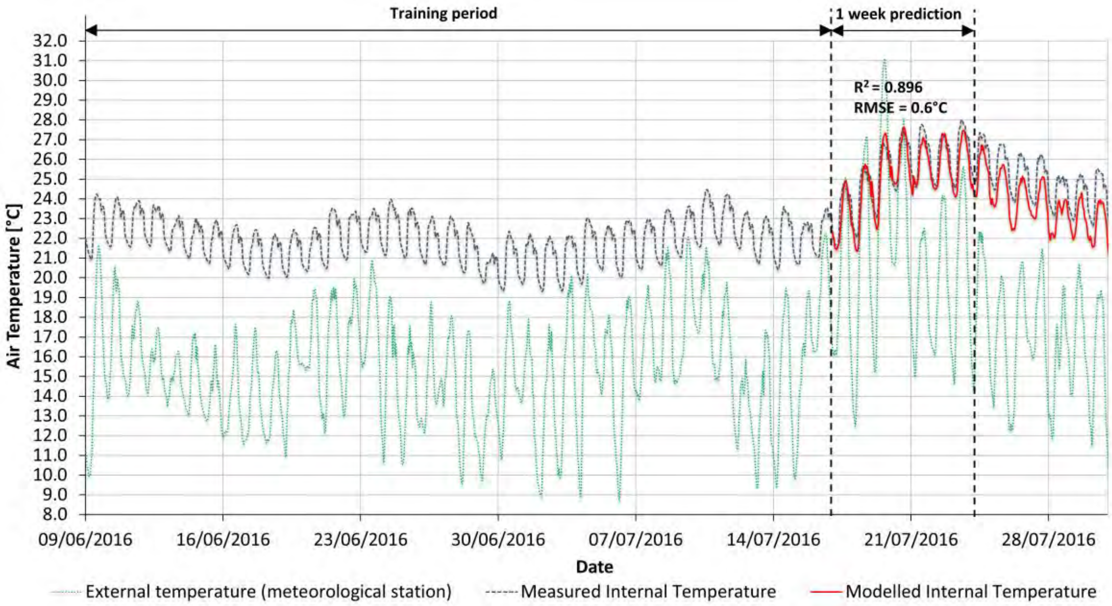

Figure 4. Measured and modelled temperatures – Example showing model dry bulb temperature predictions for the living room using meteorological interpolation (SB-CC-WIT)

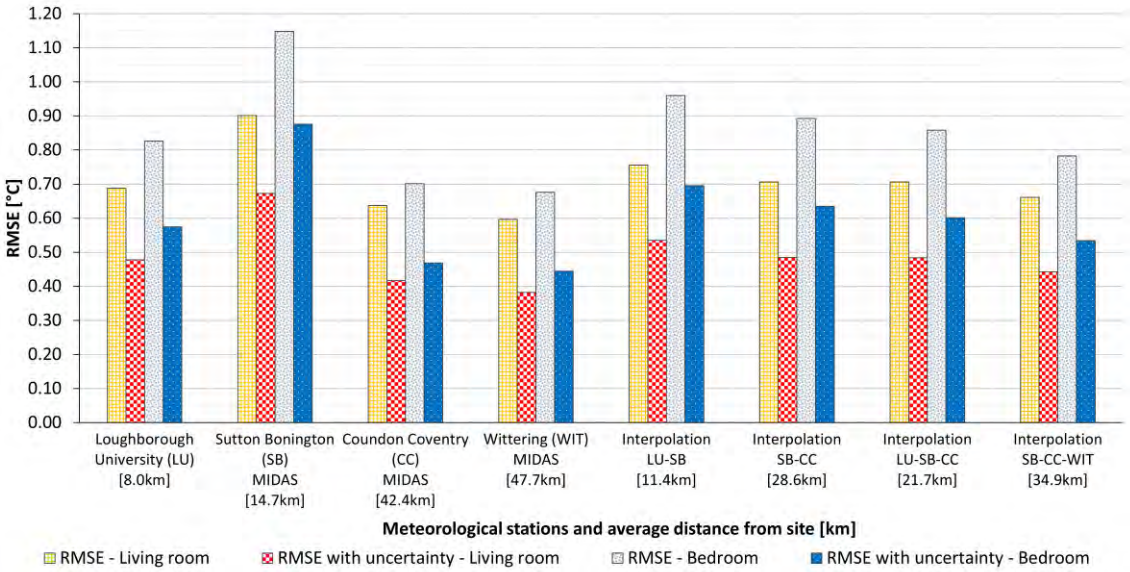

Figure 5. RMSE of the predictions in the LR and BR, with and without considering the uncertainty range.

Conclusions and recommendations

This study has shown that the newly developed ITCC empirical TSAM model is able to accurately predict the internal temperature evolution of a dwelling, for a period up to 7 days in the living room and bedroom of this test house. It also highlights the inaccuracies that are introduced to the model when data from 'near neighbour' meteorological stations are used. Triangulation of the weather data inputs improved the model's predictive accuracy whilst reducing the variability and uncertainties associated with the results. For more robust and prolonged predictions, further model development is needed in order to further improve predictive accuracy during sudden spikes in the external temperatures.

Acknowledgments

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Effect of thermal diffusivity of insulating materials on room free-float temperature with façade external insulation

Emanuele Habib[1], Marta Cianfrini[2]

[1] DIAEE – Sapienza Università di Roma, Italy, emanuele.habib@uniroma1.it
[2] DIMI – Università degli Studi Roma Tre, Italy

Abstract: External insulation of building façade is widely used to reduce heating energy demand in buildings. Usually, its design concerns only thermal transmittance, while transient thermal behaviour is commonly addressed only as dumping factor or time lag of outdoor heat wave. During summer, in many mild climates, outdoor daily mean temperature is close to comfort temperature. Yet, even though mean heat transfer through building envelope is null, heating during daytime may lead to positive cooling loads or discomfort temperatures in non-conditioned rooms. In residential buildings internal loads are usually very low, so the most relevant loads are heat transfer though outer facades. Moreover, where there is no cooling, wall dumping factor is not meaningful to evaluate the thermal performance of wall insulation, as it is referred to constant indoor temperature. In this framework, a model of a room with a single outer wall has been developed to study the effect of insulating material on free-float temperature. Transient heat transfer through the envelope as well as through inner walls is considered to model indoor air temperature. Different localities in Italy and commonly used insulating materials are considered.

Keywords: Overheating, Thermal comfort, Night cooling, Dynamic effect of thermal insulation, multi-layered walls

Introduction

External insulation of building façade is widely used to reduce heating energy demand in buildings. Actually, in conventional buildings, heating energy demand is mostly due to heat transfer through the building envelope. So, increasing thermal resistance of outer walls by applying thermal insulation reduces heat transfer rate. In order to avoid interstitial moisture condensation and to reduce thermal bridges, insulating panels are often applied outside.

Besides, in many parts of Europe, in summer, climate is quite mild so that heat transfer is from inside to outside during the night as outdoor temperature decreases under indoor comfort temperature. Moreover, in non cooled rooms, indoor temperature fluctuates as a result of inner loads, solar loads and heat transfer through building envelope. So, even during daytime, heat transfer is often from inside to outside. Therefore, insulation of outer walls reduces outgoing heat transfer through building envelope, leading to an increase of indoor temperature.

The risk of overheating in highly insulated dwellings have been pointed out in a number of reports concerning different European Countries (Isaksson & Karlson, 2006; Schmitt et al., 2007; Janson, 2010; Larsen & Jensen, 2011; McLeod et al., 2013). These finding suggests that the thermal insulation of outer walls reduces heating energy demand but may provoke an increase in cooling demand, urging the application of cooling systems.

Anyhow, even in this case, the new cooling energy demand is usually quite low, so yearly energy balance is positive.

As stated, during summer heat transfer through an outer wall may be either inwards or outwards, changing direction during the same day. Thus, transient behaviour of each layer is relevant for indoor temperature behaviour, including insulating layer.

In this framework, different materials, commonly used in outer insulation of building envelope, are analyzed in order to highlight their effect on indoor temperature, presuming there is no cooling. A standard apartment bedroom is considered.

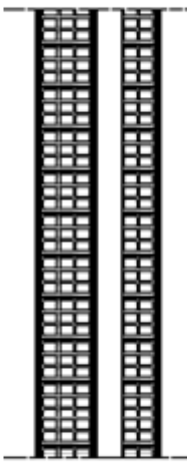
Mathematical Formulation and Computational Procedure

The room is considered to be 5 m wide and 4 m deep with a 3 m height. Only one wall is outfacing in which there is a 1.25 m^2 window. Other walls, the roof and the floor are supposed to adjoin rooms that are almost at the same temperature, so that heat transfer through them may be neglected. In order to evaluate their contribution to indoor heat capacity they are modelled assuming that the midplane is adiabatic.

The outer wall is the type known as “a cassetta”, made of two layers in bricks and a wide hollow-space, that is the most common one among reinforced concrete skeleton buildings built between the end of WWII and the arising of the energy crisis in mid '70s. The composition of the wall is sketched in fig. 1. In the cavity, heat transfer occurs by natural convection and radiation at the same time. As radiation heat transfer is prevalent and its thermal capacity per unit volume is much lower than other layers, for calculation purpose it may be treated as a homogeneous layer made of an opaque material with an equivalent conductivity evaluated from eq. 1:

$$k_{eq} = h \cdot s_{cavity} \tag{1}$$

where , *k* stands for thermal conductivity, *h* for combined convection and radiation heat transfer coefficient in the cavity, *s* for thickness.



Material	Thickness mm	Thermal conductivity W/m·K	Density kg/m^3	Specific heat capacity J/kg·K
Plaster	15	0.9	1800	1000
Bricks	120	0.4	750	836
Cavity	60	0.3	1.2	1000
Bricks	80	0.4	750	836
Plaster	15	0.8	1400	1000

Figure 1. Outer wall composition. Data are outside to inside

The window is made of two glass layers with low emissivity inside coating (0.1 emissivity), Argon filling, and is assumed to be completely shaded from direct sunlight.

An energy renewal intervention by application of 60 mm thick insulating panel on the outer face is considered. Expanded polystyrene (EPS), Expanded polyurethane (EPU), and a double density Mineral wool panel (MWP) are considered, with properties stated in table 1, together with insulated wall thermal transmittance.

Table 1. Properties of insulating materials

Material		**Thickness** mm	**Thermal conductivity** W/m·K	**Density** kg/m^3	**Specific heat capacity** J/kg·K	**Thermal diffusivity** m^2/s x10^6	**Thermal transmittance** W/m^2·K
EPS		60	0.036	18	1450	1.38	0.39
EPU		60	0.028	35	1464	0.55	0.33
MWP	outer layer	20	0.031	120	1030	0.25	0.37
	bulk layer	40	0.035	70	1030	0.49	

Thermal field equation in each wall layer is described by a Cartesian one-dimensional Fourier's equation for conducting fields:

$$\frac{\partial^2 T}{\partial x^2} = \frac{1}{\alpha} \times \frac{\partial T}{\partial \tau} \tag{2}$$

where, T for temperature, α for thermal diffusivity, and τ for time. At layer junction, heat flux conservation is given by:

$$k_a \frac{\partial T}{\partial x}\bigg|_a = k_b \frac{\partial T}{\partial x}\bigg|_b \tag{3}$$

where subscripts a and b stand for the two neighbour layers. Outdoor boundary condition is combined convection and radiation heat transfer coefficient:

$$h_o \cdot (T_{outdoor} - T) + a \cdot W = -k \frac{\partial T}{\partial x} \tag{4}$$

where h_o is outdoor heat transfer coefficient, a is absorption coefficient of solar radiation, and W is solar radiation specific power. Indoor boundary condition is convection heat transfer to room air, and radiation heat transfer to the other surfaces of the room, evaluated through its mean radiant temperature:

$$-k \frac{\partial T}{\partial x} = h_i \cdot (T - T_{room}) + h_r \cdot (T - T_{mr}) \tag{5}$$

where h_i is indoor convection heat transfer coefficient, h_r is indoor radiation heat transfer coefficient, T_{room} is room air temperature, and T_{mr} is mean radiant temperature, defined from eq. 6:

$$T_{mr} = \frac{A_o \cdot T_o + A_i \cdot T_i + A_w \cdot T_w}{A_o + A_i + A_w} \tag{6}$$

where subscripts o, i and w stand for outer wall, inner wall and window, respectively. Room air temperature is assumed to be uniform and calculated through energy equation:

$$\begin{aligned} V \cdot \rho_a \cdot c_{p_a} \frac{dT_{room}}{d\tau} &= \\ &= h_i \cdot A_i \cdot (T_i - T_{room}) + h_i \cdot A_o \cdot (T_o - T_{room}) + h_i \cdot A_w \cdot (T_w - T_{room}) + \dot{Q}_i + \dot{Q}_V \end{aligned} \tag{7}$$

where V is room volume, ρ_a is room air density, c_{pa} is room air isobaric specific heat, $\dot{Q}_i$ *is* inner loads due to people, lighting and appliances, and $\dot{Q}_V$ is ventilation heat transfer, given by eq. 8:

$$\dot{Q}_V = n \times V \times \rho_a \times c_{p_a} \times (T_{outdoor} - T_{room}) \tag{8}$$

where subscripts n is room ventilation rate (air changes per unit time). In the window, conduction heat transfer is neglected, assuming each glass to be isothermal.

Governing equation, along with boundary and initial conditions stated above, are solved through a control-volume formulation of the finite-difference method. A second-order backward scheme is used for time stepping. Auxiliary temperature nodes at materials interfaces are used. The discretized equations lead to a linear system that has been solved with Thomas algorithm with a specifically developed Matlab code.

The code was checked against reference simple analytic solutions found in (Carslaw & Jaeger, 1959) to get the optimal mesh-size and time step. In order to assure that the error to the analytic solution is less than 10^{-3}, 30 s time step with an x-wise step given from eq. 9 has been found to be a good balance between calculation time and solution accuracy.

$$\Delta x = s\sqrt{\frac{1.5}{\alpha \times \Delta\tau}} \tag{9}$$

Results and discussion

Simulations with typical year outer climate in different cities in Italy with usual ventilation and inner loads, as well as with 24 hours sinusoidal solicitation response are performed. While the former simulations provide data close to effective use conditions, the latter are useful to understand the phenomenon. All simulations are performed assuming 0.3 vol/h continuous air change rate.

Sinusoidal solicitation - 24 hours period

A 24 hours long sinusoidal variation of outdoor temperature is considered with 24°C minimum and 34°C maximum. No sunlight nor inner loads are introduced in the calculation. Simulation is reiterated up to periodic regime with a maximum variation of any temperature lower than 10^{-3} K. Periodic regime is reached after 15 to 25 periods.

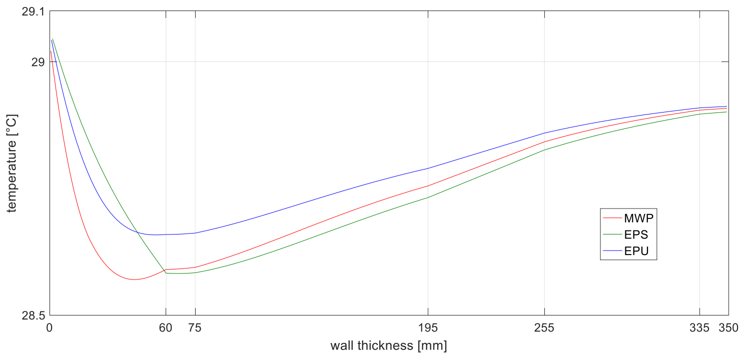


Figure 2. Temperature fields within the outer wall at solicitation beginning (outdoor temperature 29°C)

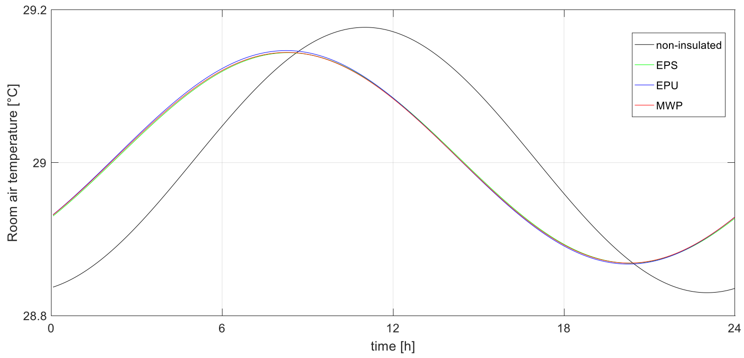


Figure 3. Room air temperature during a full period

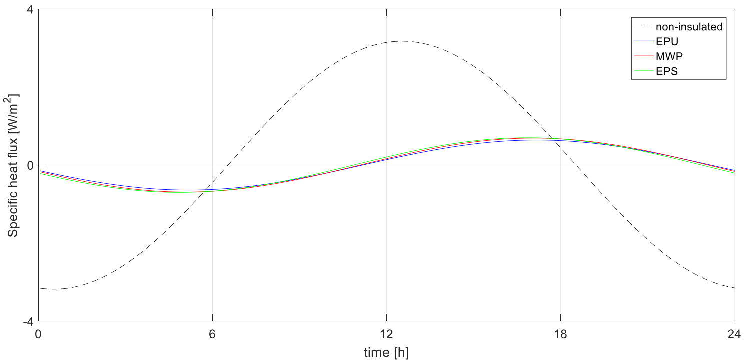


Figure 4. Heat transfer through outer wall during a full period

Temperature fields with the three different insulating materials after 4 minutes from solicitation beginning, when outdoor temperature is equal to the mean 29°C, is shown in fig. 2. Temperature fields in the bricks show a lower gradient in EPU than in the other two. This is clearly due to the higher thermal resistance introduced by this insulating material that is due to its lower thermal conductivity. Besides, MWP show a thermal inertia that lead to a delay in heat wave crossing, so that it is still cooling the outer bricks, while in EPU and EPS panels heat transfer direction is already fully inverted.

As far as the effect on indoor air temperature is considered, the differences between insulating materials smooth down, almost vanishing as shown in fig. 3. All insulating materials share almost the same behaviour. It might be surprising that insulating the outer wall leads to a reduction in heat wave time lag with respect to non-insulated outer wall. It must be considered that room air temperature is due to the combined effect of heat transfer through the outer wall altogether with heat transfer through the window and by ventilation. Insulating the wall reduces its contribution to room temperature, so the effect

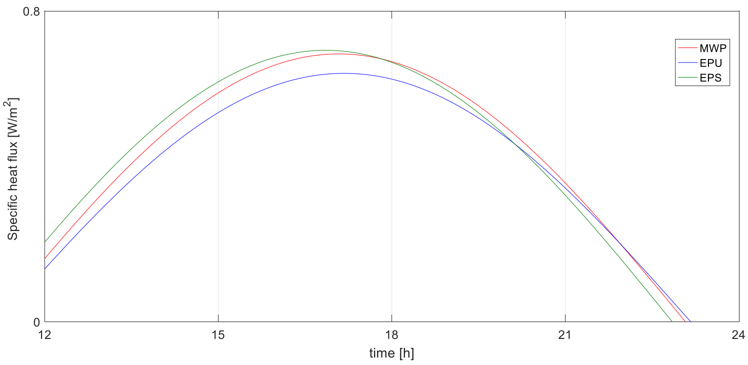


Figure 5. Highlight of peak heat transfer through outer wall for different insulating materials

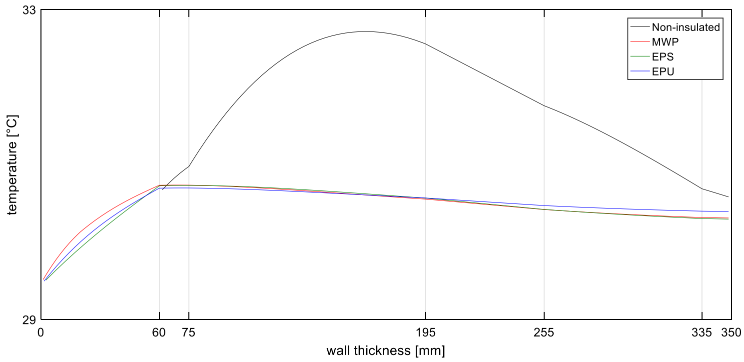


Figure 6. Temperature fields within the outer wall on the hottest day in Rome at 8 p.m.

of the other two heat transfer modes, that share a negligible time lag, take effect earlier, bringing forward the temperature maximum.

Considering solely heat transfer through the outer wall, as shown in fig. 4, the effect of outside insulation is highlighted. Outer wall contribution to heat transfer is strongly reduced, increasing its time lag from almost 7 hours to almost 11 hours. Focusing on the behaviour of different materials it may be seen from fig. 5 that while MWP and EPU share the same time lag, while EPS time lag is one hour shorter.

Data show quite clearly that insulating materials contribution to time lag is mainly due to their thermal resistance. Yet, using materials with lower thermal diffusivity (like MWP) increases time lag further.

Typical year climate

Summer period in a typical year is considered for Milan, Rome, Naples and Palermo, whose mean outdoor temperatures in July and August are given in table 2. The outer wall is assumed to be South facing. Inner loads are assumed to be equal to 150 W from 10 p.m. till 7 a.m. Simulations are performed from 1st May till 30th September to simulate the whole summer period.

Table **2**. Monthly mean temperatures

	Milan	Rome	Naples	Palermo
July	22.3°C	24.1°C	24.6°C	25.6°C
August	21.8°C	24.4°C	24.4°C	26.2°C

Temperature fields in the outer wall for different insulating materials on the hottest day in Rome at 8 p.m. show a decrease in inwards heat transfer rate with some residual thermal inertia in MWP insulating, as shown in fig. 6.

In order to compare the influence of insulation and differences between insulating materials, cumulative indoor temperature distributions are generated, as shown in fig. 7, illustrating the cumulative time in which it is higher than the temperature on the abscissa. It is evident that insulating the outer wall increases indoor temperature as in non air conditioned rooms mean heat transfer direction is outwards. Thus, wall insulation implicates a higher indoor temperature to restore heat transfer rate.

The influence of climate on performance of different insulating materials may be highlighted by comparing cumulative time in which indoor temperature is higher than 28°C,

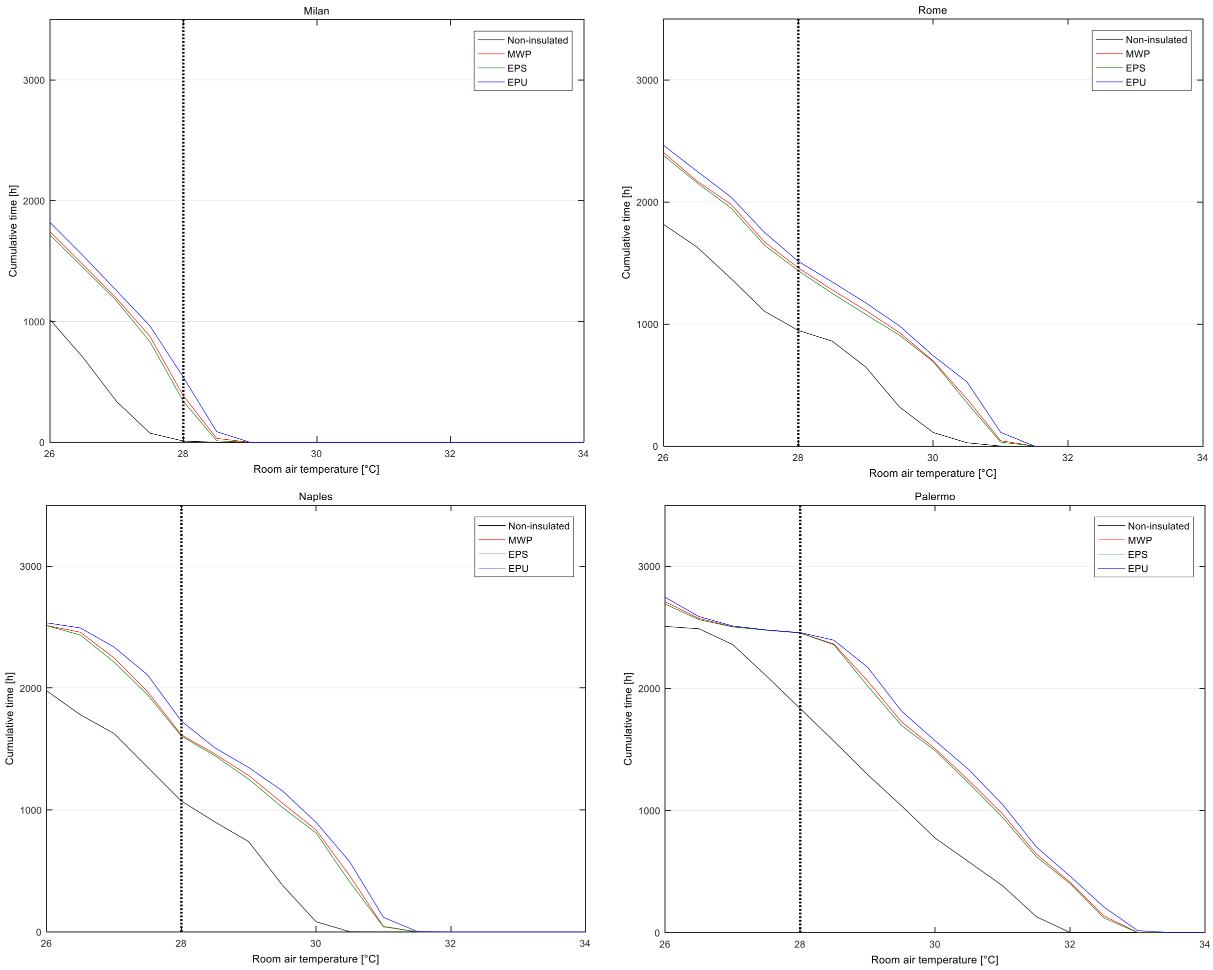


Figure 7. Outer cumulative indoor temperature distributions

that may be chosen as indoor distinctive temperatures for summer, as depicted in fig. 8. It is evident that in Palermo all insulating materials perform in the same way with a 33% increase in cumulative hours with indoor temperature higher than 28°C. As Palermo has a quite hot climate in summer, heat transfer through the outer wall is less relevant on overall behaviour. In Rome and Naples, that have milder summer climate, the higher insulation provided by EPU increases room overheating, especially in Naples in which July is even hotter than August. The overheating due to MWP and EPS, slightly lower in Naples than in Rome, suggests that their effect may be more relevant on a peak period of outdoor temperature rather than on a high mean value.

Conclusions

Simulations of temperature fields and indoor air temperature for a sample room has been performed with a finite difference formulation of heat transfer equations.

Sinusoidal solicitation show that outer insulation modifies indoor temperature evolution reducing room temperature time lag as heat transfer due to ventilation and windows become more relevant. Yet all insulating materials provide almost the same increase in wall time lag, slightly lower for EPS insulation. Mineral wool shows a higher thermal inertia, although it is not enough to change wall behaviour, it may compensate a slightly lower thermal resistance.

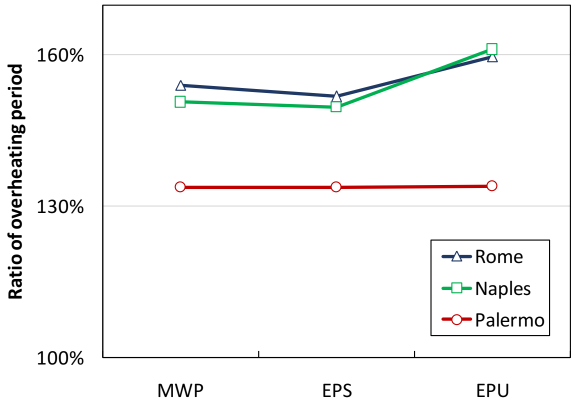


Figure 8. Cumulative time in which indoor temperature is higher than 28°C, ratio to non-insulated wall

Typical year simulations for different climates in Italy with common inner loads show a pronounced overheating, especially in the least hot climate. In Naples and Rome, although monthly mean temperatures are similar, the effect of different insulating materials is not the same. The higher thermal resistance provided by EPU lead to a longer overheating, while MWP and EPS provide a longer overheating in Rome than in Naples, although July monthly mean temperature is lower.

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Design to Thrive

A Practical Method to Design Building Shade

Pablo La Roche[1], Arianne Ponce[2]

[1] CallisonRTKL and Cal Poly Pomona Department of Architecture. California, United States of America. pablo.laroche@callisonrtkl, pmlaroche@cpp.edu
[2] CallisonRTKL

Abstract: Solar radiation entering through windows can contribute a significant amount of heat into the building, which is a liability when cooling is needed during overheated periods. In warm climates it is important to control solar radiation, especially through windows, with properly designed shading systems that also allow daylight during the whole year. There are several manual and digital tools to design shading systems, however, manual methods are typically based on rules of thumb and simplifications that do not provide the accuracy needed to design the high performance buildings that we need today. Digital methods are accurate when done correctly, but also require more time, that is not always available, and a more sophisticated knowledge of certain tools. This paper discusses a process to design static shading systems for buildings that provides accuracy and speed. The process follows four general steps: a) climate analysis b) solar study c) shade design, e) performance evaluation. After this process the shade might be redesigned or adjusted if required. Examples from practice and academia will be included in the presentation.

Keywords: Shading, building simulation, building overheating, low energy design, design for warm climates

Introduction

Uncontrolled amounts of glass in buildings, though attractive, can lead to overheating and glare, forcing occupants to close the blinds, which then usually stay closed, blocking views and daylight, negating the purpose of the window. However, solar radiation can be controlled during the overheated period with properly designed shading systems that also provide daylight and views during the whole year.

Heat is exchanged through a window by conduction, convection, and radiation. Depending on the size, orientation, and quality of the window, this heat can be a large percentage of total heat gains and losses in a building. Gains should be reduced in the summer and shade is one of the most effective strategies to reduce these heat gains. A well designed shade should reduce solar gains during the overheated period while maybe allowing them during the under-heated period. In an air conditioned building shade reduces cooling energy and GHG emissions, while in a naturally ventilated building it reduces overheating. Shade can also improve comfort in outdoor spaces during the overheated period.

From earliest history, all buildings in warm climates have tried to protect themselves from the sun. Socrates, more than 2400 years ago stated “is it not pleasant to have the house cool in the summer and warm in the winter?” “Now in houses with southern orientation the sun’s rays penetrate into the porticoes, but in summer the path of the sun is right over our heads and above the roof so we have shade….To put it succinctly, the house in which the owner can find a pleasant retreat in all seasons is at once the most useful and the most beautiful.” (cited from Perlin, 2013). Le Corbusier, with his brise soleil was one of the first contemporary proponents of shading in buildings, and examples include the Ministry of Education and health in Brazil in 1936 and the Unité d'habitation in Marseille in 1952. The Olgyay brothers (1957, 1963) rigorously studied shading systems, proposing responses that responded to orientations, and a method to design them based on the relationship between external climate and a comfort zone of 21.1 °C, using shadow masks plotted in a sun path diagram.

Givoni continued developing the shadow masks and studied the effect of fixed shading devices in different orientations (Givoni, 1976). For a location in Israel at a latitude of 32 N he stated that a horizontal shade works better on the south (equatorial facing façade); a vertical fin on the west side of the windows was better to block summer afternoon sun on the north façade; and that east and west were better shaded by a horizontal element combined with a vertical oblique to the south. Givoni also stated several now commonly accepted guidelines regarding shading devices (Givoni, 1998):

- External shading is much more effective than internal shading.
- The performance difference between external and internal shading increases with darker shade material.
- The efficiency of external shading increases with darker colours. However, these can overheat and radiate longer wave radiation to the interior when the window is open.
- The performance of internal shading increases with lighter colours.
- Efficient external shading can eliminate about 90% of solar radiation
- With inefficient shading, such as dark internal devices, the solar gain inside the space will still be 70-80% of the striking radiation.

Ed Mazria included in his book (Mazria, 1979) shading calculators, a method to plot the skyline, and a calculator to estimate the amount of solar radiation falling on surfaces with different inclinations, from vertical to horizontal at 30 degree intervals.

The effects of shade combined with thermal mass and night ventilation have also been quantified and the performance of night ventilation increases significantly with shade, either fixed or automatic (La Roche, Milne 2004) (La Roche, Milne 2005).

Andrew Marsh (Marsh, 2005) provided a quick and easy way to calculate shadow masks inside the Ecotect software environment. A shadow mask is a graphical mechanism to record which parts of the sky are visible from a particular point in the building model. For any given set of obstructions, this information can be overlaid on a sun-path diagram indicating shade over a given point at any time of the year. To improve the precision of the numerical analysis and increase computational speed, Marsh divided the sky into discrete segments, storing shading values for each one, and implemented algorithms to calculate the effect of diffuse, direct and reflected solar radiation on surfaces. He overlay this information on the sun-path diagram, providing additional data, beyond simply unshaded or shaded.

As weather files with solar radiation data have become more common, the implementation of software for solar and shadow studies continued developing. A prototype tool that evaluated solar radiation on complex building envelopes using Maya, a three dimensional modeling and animation software was developed at UCLA (Da Veiga, La Roche 2003). In this program, a fitness function rated the individual and overall performance of the proposed building envelope as a function of solar radiation levels. The goal was to design a tool that would generate the most effective form that would respond to specific solar geometry and solar radiation. Shade design tools such as Shaderade (2011, Sargent, J., et al) based on Rhinoceros® and EnergyPlus have been developed to assess the thermal desirability of solar transmittance through any potential shading volume or surface. Linking parametric design software, energy simulation tools, and optimization algorithms allows for the customization of shading devices to reduce anticipated energy use (Glassman E., Reinhart C., 2013).

In a warming world, overheating is becoming more important at all latitudes and locations, even in areas which traditionally did not have this problem. Studies in a prototype tested across different climates in Europe indicate that overheating is already a problem (Brotas, L., Nicol, F., 2015), (Brotas, L., Nicol, F., 2016). This is further exacerbated under climatic predictions for 2030, 50 and 80. Brotas and Nicol propose several low carbon and economically viable solutions such as night cooling, cross ventilation, and shading to reduce the danger of overheating. They state that "shading systems are fundamental to mitigate solar access to the building on hot periods and where possible should be positioned externally to minimize heat entering the space." (Brotas, L., Nicol, F., 2016). They tested several models and results showed that a building that complies with current standards and adopts passive strategies (e.g. natural ventilation and shading, especially external shading), is likely to cope with overheating in line with climate predictions. External shading had the highest impact in preventing overheating.

Research by Gupta el al, (2016) also suggests a mismatch between overheating risk predicted using climate modelling and the actual occurrence of overheating. His study focused in facilities for the care of elderly individuals which have an increased heat-related mortality and morbidity and health related risks. While climate modeling suggests that overheating is not a significant risk in the UK until 2080s, measured data indicated that there is a current risk of overheating in care facilities for the elderly, especially during short heat waves (lasting two to four days).

Design Method

Shade must be designed appropriately, considering both climate and building type. There are two major approaches for the design of shading systems: a) manual methods based on rules of thumb and b) parametric design methods that link software with energy simulation tools. Methods based on rules of thumb are usually found in existing literature and websites and followed by many designers. Due to simplifications they are not sufficient to design the high performance buildings that we need today and in some cases might even provide incorrect guidance. On the other hand parametric design methods linked with energy simulation tools can provide very accurate results but require more time and knowledge to implement. This approach can lead to very interesting designs but also to erroneous results if assumptions are incorrect during the process. Because the method uses sophisticated tools the designer might think that a shade system is very accurately designed while in reality there are major flaws in it.

Shading Devices can be fixed and operable and internal and external. This paper will discuss the process of designing fixed external shading devices for buildings. The method can also be used for the design of shade in outdoor spaces with some variations. The process uses analogue and digital tools, following several steps: a) climate analysis and determination of overheated and under-heated periods; b) solar analysis; c) shading design; d) performance evaluation; e) redesign/adjustment (Fig 1).

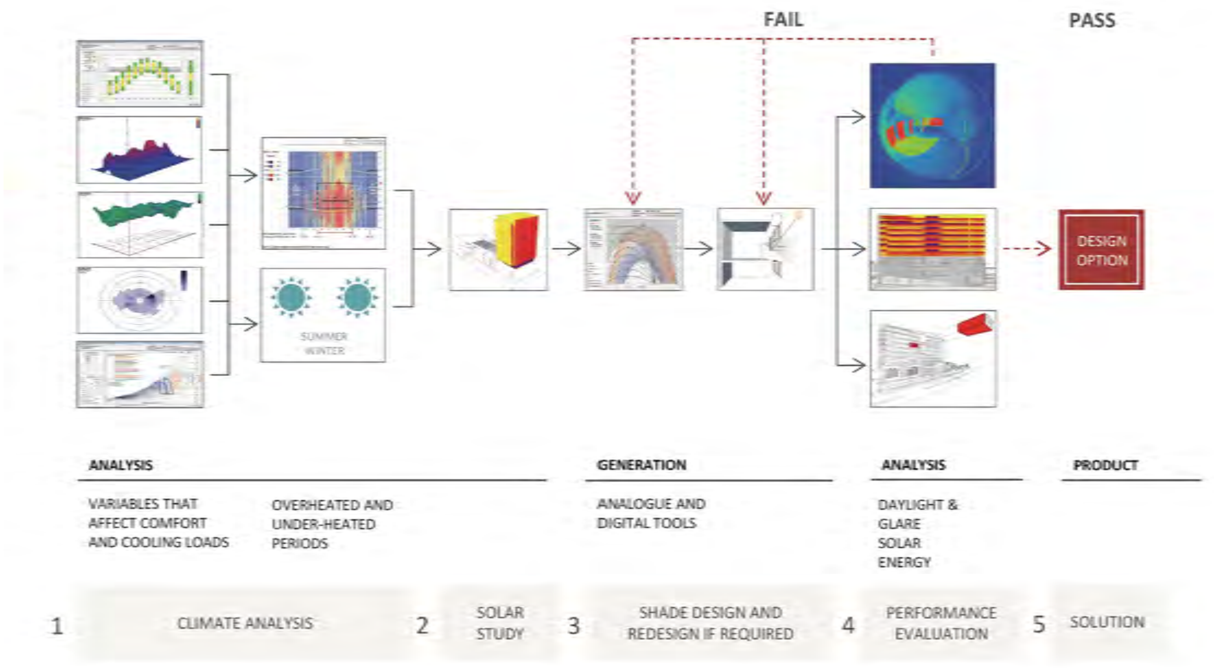


Figure 1. Design Process for Fixed Shading Devices

Climate Analysis

The process begins with a climate analysis. The most important factors to analyse in climate are those that affect thermal comfort, energy consumption and GHG emissions in buildings. Typically temperature, direct and diffuse solar radiation, relative humidity, and wind speed and direction are studied using a weather file. EPW weather files can be obtained from several sources including the U.S. Department of Energy at https://energyplus.net/weather. Temperature and solar radiation (direct and diffuse) are critical to accurately determine cooling and heating seasons and when solar radiation should be promoted or blocked. For analysis there are several free tools. Climate Consultant from the University of California Los Angeles, is very easy to use and also provides design advice based on the climate, now linking to the 2030 Palette with examples of strategies for buildings in different climates (http://2030palette.org/). A tool developed at MIT allows for visualization of EPW files https://mdahlhausen.github.io/epwvis/. Grasshopper with Ladybug provide a relatively easy to use option to visualize weather data.

Climate data helps to determine the overheated and under heated periods, which are used for summer and winter insolation analysis, self-shading studies, determination of critical façades, and the design of shading options for windows. Overheated and under heated periods are calculated differently for outdoor spaces or buildings. Non-building outdoor shade requirements are better defined by the environmental variables that affect thermal comfort or thermal stress (temperature, radiation, air velocity, relative humidity), while the building shade period is better defined by the cooling requirements of the building or by indoor thermal comfort. These are also affected by environmental variables, but regulated by the building. Outdoor spaces might have similar but not exactly the same shading periods.

There are several methods to determine the overheated period in buildings. Reinhart (2014) describes a solstice method, a degree day method, and a thermal balance method. The authors use similar methods but use an outdoor temperature method instead of a solstice method. The goal of all of these is to predict the shade period to reduce solar gains, reducing cooling loads and overheating. This period will be defined by a start and end date and a start and an end hour. The timetable plot of bioclimatic needs proposed by Olgyay can be used to show these in one chart. Static devices will always be symmetrical around the summer solstice but unfortunately, temperature will not. This means that a static shade will probably provide excessive or insufficient shade during some part of the year. The following paragraphs describe some of the methods used by the author to determine the overheated period.

Exterior temperature method

In this method the overheated and under-heated periods are determined using the outdoor dry bulb temperature and its relationship to a reference temperature, which is usually linked to the balance point temperature. The balance point is the temperature at which a building needs neither heating nor cooling for comfort because the internal gains equal the losses. The assumption is that when outdoor temperature is above the reference temperature the building will overheat and need air conditioning to maintain comfort. Shade during this period would reduce cooling loads in mechanically conditioned buildings and improve comfort in naturally ventilated buildings. This method is very easy to implement but it does not consider different types of buildings with differing envelopes and heat capacities, or different schedules and internal loads. Thus, this method is more effective when implemented on light weight buildings.

The Olgyay brothers proposed a reference balance point of 21.1°C in temperate areas, and higher in buildings closer to the equator (Olgyay, 1963). They plotted this overheated period in a matrix divided in hours and months, which they called the timetable plot of bioclimatic needs. The balance point in current buildings is now much lower than 21 °C due to buildings with better envelopes. The method however, can still be implemented using a different value and Climate Consultant provides an option to implement it changing the value of comfort low to the balance point temperature and using the sun shading chart. This chart shows every hour of the year divided in two six month periods, from December 21 to June 21 and from June 21 to December 21. It provides the position of the sun and shade requirements for every hour of the year based on outdoor temperature divided into one of three options, warm/hot (shade needed), comfort (shade helps), and cool/cold (sun needed) according to the comfort model selected. It is possible to use this sun shading chart to define the months and the hours during which shade is required based.

Degree day method

This methods uses heating and cooling degree days to determine the overheated period. Heating and cooling degree days are based on balance point temperatures and provide an estimation of heating and cooling requirements in a specific climate. Heating degree days (HDDs) describe the average daily temperatures below a base temperature and cooling degree days (CDDs) for a specified base temperature describe the average daily temperatures above a base temperature. The base temperature for Heating Degree Day calculations is typically the lower limit of the balance point temperature and the base temperature for Cooling Degree Day calculations is typically the upper limit. When the outdoor temperature is between these two values, the building will typically not need mechanical heating or cooling. Monthly heating and cooling degree days are plotted for the whole year using degree day tables, or online sources of data. In climates that need both heating and cooling there will be one or more months in the spring and fall in which there will be both heating and cooling. The overheated period starts when cooling degree hours appear in spring and ends when they disappear in the fall. During this period there might be overlapping of HDD and CDD, so the designer must select when there is sufficient need for cooling to require shading, which could be when the difference between them reaches a predetermined value. The designer may decide to define a shorter shade period based on other considerations such as daylight, unequal distribution of CDDs around the solstices, adding interior operable blinds, or costs. Climates with high CDDs all year also require shading during the whole year.

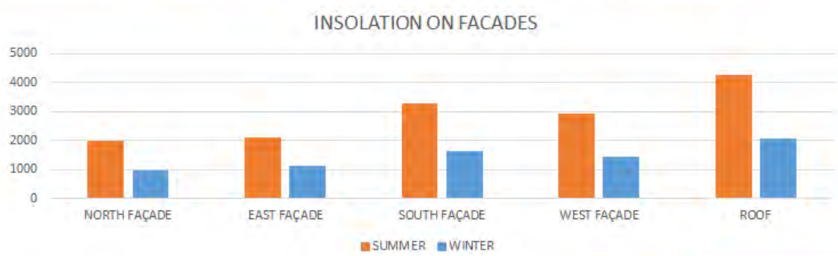
The Energy Model method

This method is more precise but requires energy modelling software to determine cooling and heating loads. It provides more precision than the balance point method because it accounts for the specific properties of the building being analysed that are not accounted for in the degree day method. Annual building analysis using a local weather file and a simplified building design, with envelope and internal loads similar to the project will provide a monthly breakdown of heating and cooling energy to determine cut off months for the shading system. These values can also be converted to carbon emissions using appropriate factors, allowing to compare effects from different sources in a common unit of measure, CO2e.

Solar Study

Façade solar studies, permit to quickly determine critical orientations that require more solar protection. Solar studies should be done for the previously defined overheated period using one of the methods previously described. Values can be expressed as average daily per unit of area or total values for the analysis period. There are several software that perform solar studies such as IESve and DIVA. Fig 2 shows some views of a solar study and bar charts with winter and summer average daily solar radiation (Fig 3).

Figure 2. Example of solar Studies on Building Surfaces



Summer:
Roof receives most solar radiation. Most critical facade is south followed by west.

Winter:
Heat gain on the facades averages 50% of summer values. Highest value is also on the roof but followed very closely by the south and then the west facades. Solar heat gain in the winter could be beneficial depending on internal loads. Glare should be controlled.

AVG. DAILY RADIATION (Wh/m²)		
SURFACE	SUMMER	WINTER
NORTH FAÇADE	1988	940
EAST FAÇADE	2090	1095
SOUTH FAÇADE	3271	1622
WEST FAÇADE	2896	1413
ROOF	4238	2030

Figure 3. Example of data from solar studies on building surfaces in Fig 2

Shade Design

The next step is to design the shade component(s) based on orientation and dimensions of the surfaces requiring shade and seasonal requirements. Vertical and horizontal shadow angles should be calculated using one of several methods. Shadow masks are useful because they show annual shading for a whole year in one figure. Climate Consultant permits to test vertical and horizontal shadow angles using outdoor temperature. Multiple options can then be designed and dimensioned using proposed vertical and horizontal shade angles. It is also useful at this moment to propose shading design goals, for example percentage reduction over a given period. Dimensions of shade components are then designed as a function of the dimension of the window (or element to be shaded) and the vertical or horizontal shadow angle. For example, to calculate a horizontal shade element:

$$OP = HP/\tan VSA$$

Where OP is the horizontal overhang projection and HP is the distance of the horizontal overhang from the shading element to the bottom of the window and VSA is the vertical shadow angle.

To calculate a vertical shade element:

$$FP = WW/\tan HSA$$

Where FP is the fin projection, or fin size, and WW is the width of the window that must be protected by the shadow of the fin and HSA is the horizontal shadow angle.

Alternatively, visual trial and error with a 3d modelling tool or a parametric method can be used to determine optimum dimensions.

Performance Evaluation

Shading options should be tested for overall energy consumption, illuminance and luminance levels. A simple shoebox modelling tool like COMFEN is a quick and easy way to do this as are other energy modelling tools. A physical model can also be used for daylight studies and a heliodon for shadow studies in analogue models. If there are no tools available to calculate energy use and daylight, a comparison of the solar gains on the façade with and without shade is useful. The façade with the least amount of incident radiation on the envelope during the overheated period is the most effective option. This number can be described as a percentage reduction (Fig 4). The percentage reduction at peak cooling loads is also helpful.

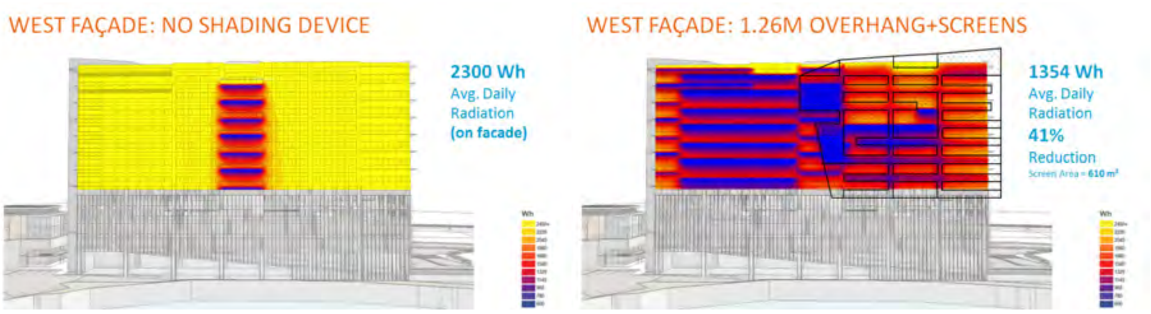


Figure 4. Solar Studies Comparison of Design Options

Final Solution or Return to Adjustment

If the design provides either insufficient shade or too much shade, it must be redesigned and re-evaluated, returning to step 3, assuming the overheated period is correctly calculated.

Conclusion

Shade is an effective strategy to reduce solar gains. It is clear that climate change will require buildings that are better shaded to reduce GHG emissions and increase indoor comfort. However, shade components cannot be too large so that they block winter gain and must also be right sized for good daylight. The method described in this paper is not prescriptive, instead it is a guide in which different tools can be plugged in and out following the indicated steps. Following this process will produce lower carbon buildings which can still have transparency in their façades providing occupants with good daylight and views.

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Experimental study of the roof thermal performance influence over the mean radiant interior temperature of an industrial building

Jefferson Torres[1], Helena Coch[1], Isabel Crespo[1] and Antonio Isalgué[2]

[1] Architecture & Energy, School of Architecture, Polytechnic University of Catalonia, Barcelona, Spain, Av. Diagonal, 649, 7th floor. 08028;
[2] Applied Physics Department, Polytechnic University of Catalonia, Barcelona, Spain, Pla del Palau, 18. 08003.

Abstract: Industrial building rehabilitation is one the latest trends within the field of sustainable development. However, these interventions often disregard the issue of user comfort, despite being the most important factor of energy efficiency. This work deals with the assessment of the indoor thermal conditions of a restored industrial building, considering not only air temperature but also mean radiant interior temperature. The research focuses in the influence of the radiative performance of the saw tooth roof of this building regarding these conditions. Results show that the analysed thermal parameters depend directly on the roof thermal behaviour. In fact, the glazed area of this type of roof is responsible for the 60% of the increase of the mean radiant temperature over air temperature. This result is a consequence of the high interior temperature reached by the glass panels, 47°C max, despite their northern orientation. These temperatures are a result of the diffuse radiation action and, particularly, the heat flux emitted by the opaque part of the saw tooth-roof, which significantly reduces the radiative cooling capacity of the glazed surface.

Keywords: Industrial building, mNACTEC, Mean radiant temperature, Saw-tooth roof.

Introduction

The industrial revolution, being one of the most significant changes in the history of humankind (Andrei, 2012), brought as a consequence the development of a new building typology. Large manufacturing spaces with proper lighting-spatial conditions for the implementation of productive activities were needed.

Some of these buildings have left their mark on contemporary cities through some examples of technological and aesthetic value (Fernández et al, 2016). Furthermore industrial heritage has impacted not only tangible aspects, but intangible factors too like the collective memory and identity of a place (Sutestad et al, 2016). These buildings accumulate materials, energy, and the human effort that made them possible. Their conservation and recycling for new uses is nowadays a challenge (Romeo et al, 2015).

Vapor Aymerich, Amat i Jover, designed by architect L. Muncunill, was built in 1908 in Terrassa (Spain) to operate as a textile industry, being a case of industrial architecture. This building has been restored in 1992 and converted to the Catalonia Science and Technology Museum (mNACTEC). It had a production area around 11,000 m2 which has become the principal exhibition hall of the Museum after its rehabilitation. Due to its initial purpose, the elaboration of fine textiles, this space was provided with a roof in saw-tooth. This type of roof, with its glass panels facing north, provides a large amount of natural light, and avoids the access of direct solar radiation to the interior. However, after the rehabilitation and used as Museum, the thermal indoor conditions are considered too hot in summer by visitors and workers, in spite of the scarce of sunlight entering.

The preservation of industrial buildings is considered a sustainable approach. However, the mNACTEC rehabilitation disregards its new museum's use and this could became a contradiction in terms of energy efficiency. Industrial buildings should be rehabilitated in order to be adapted to their new uses with the purpose to improve their conditions adapted to the current standards and requirements (Blagojević et al, 2016).

Even energy saving is one of the main aim in building sector, the user indoor conditions should be considered in any construction (Kalmár et al, 2011). The most important variables in regards of thermal comfort conditions are: air temperature, relative humidity, wind velocity and the mean radiant temperature (Givoni, 1994) (Walikewitz et al, 2015). Several researches have studied the influence of hot air temperatures in the interior comfort conditions on residential buildings (Beizaee et al, 2013)(Mirzaei et al, 2012). Other studies approach this issue focusing in the mean radiant temperature, assessing issues like its influence on the indoor thermal environment (d'Ambrosio et al, 2013), the interrelation with the room geometry (Kalmár et al, 2012) or the comfort limits for heated ceilings (Fanger et al, 1980). Likewise, Atmaca argues that the mean radiant temperature is a very significant factor especially in buildings whose envelopes are exposed to a strong solar radiation (Atmaca et al, 2007), like is the case of the mNACTEC roof.

In this sense, due to the proportion that the roof represents with respect to the indoor space and the singularity of its own geometry, a detailed analysis of the radiative performance of this element will be recommended.

This work addresses the issue of the interior thermal conditions, considering the possible influence of the mean radiant temperature. The specific aim of this research is to assess the influence of the radiative performance of the building saw-tooth roof, evaluating the thermal repercussions of the opaque and glass envelope surfaces.

Methodology

The methodology is based on an experimental work carried out in the mNACTEC during a period in the hottest period of summer 2015. The building is located in Terrassa-Spain, at 2°00´E, 41°33´N and 286 masl, which lies in the Mediterranean climatic zone.

The building has a main exhibition hall, 11000 m2, with 161 Catalonians vaults arranged in a grid of 7 modules in the East-West direction and by 23 modules in the North-South direction covered by a saw-tooth roof. Every module of the roof is composed by two parts: an opaque and a glass surface. The opaque surface is a semi-vault defined by a double bent built in brick. It has a 0.33m thickness composed by various layers of bricks with an air gap in the middle as shown in Figure 1c. The glass surface, oriented almost to the North (19° to the West), is formed by two simple glass panels separate by an air gap.

The experimental work of analysis of the roof radiative performance influence on the mean radiant indoor temperature has been divided in two parts. The first part focuses on the roof thermal behaviour and the second part on the thermal interior conditions. The roof measurements had the purpose to assess its thermal response to the climatic conditions to which it is exposed. Due to the singularity of its geometry the two surfaces, opaque and glazed, had been analysed separately. Solar radiation (SR), long-wave radiation (LW) and surface temperatures Ts of the opaque and glass parts (Ts.op, Ts.g) were measured, outside and inside, on this two elements that comprise the roof. The second part addresses the ambient interior conditions in order to match these results with the roof thermal behaviour. The parameters considered in this part were the mean radiant interior temperature (Tmrt) and indoor air temperature (Tai). It has been analysed the independent influence of the glass and opaque surface over the mean radiant temperature through calculations.

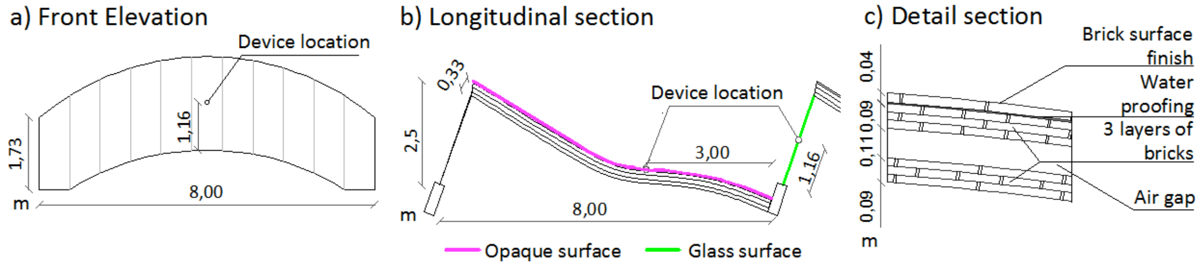

Figure 1. Construction specifications a) Front elevation b) longitudinal section and c) detail section.

The module selected from the grid to be measured was the tenth from North, and the third from West. The data of the glass surface, SR and LW was collected from June 23th to June 30th, and the outdoor surface temperature from July 1st to July 8th. The three same parameters were measured on the opaque surface from July 1st to July 8th. The data are always referred to solar time (UTC). The equipment used was: for SR a pyranometer MS-020VM with a spectral range from 350nm to 1100nm, for LW a pyrgeometer IR02 with a spectral range from 4.5 µm to 40 µm and a field view angle of 150° connected to a data logger CR800, and for the surface temperatures an external thermocouple K-type connect to a multifunctional meter TESTO 435. The first two instruments were set to collect data in 5 min and the last in 20 min intervals. Due to the difficulty of measuring the indoor temperature of the glass and opaque surfaces, an infrared thermometer was used, spectral range 8-14 µm, and emissivity calibrated at 0.90. In order to make a proper diagnostic of the radiative roof behaviour, due to the complexity of its geometry, measurements in 9 different points over glass an opaque surface were done. The measurements were done outside and inside on both surfaces, on July 9th from 09:00h to 18:00h every 30 min. This procedure was supported through thermal images with the use of a thermo-graphic-camera FLIR I7. These measurements of radiant temperatures were validated comparing the outside surface temperatures measured with the infrared thermometer and the K-type thermocouples, and the average differences were less than 0.7°C.

In regards to the ambient indoor measurements, all parameters considered in this part were collected from July 9th to July 13th. In order to assess Tmrt under indoor conditions, a frequent method validated in several studies was used (Thorsson et al, 2007) (d'Ambrosio et al, 2013) which involved the globe temperature, air temperature and air velocity. The globe and air temperature were measured using a globe thermometer WB 20SD; for the air velocity an anemometer HIBOK AM8901 range from 0.4-35 m/sec. All the equipment was placed at 2.10 m height, out of visitors' reach. The data was collected at 10 min and 60 min intervals respectively.

Finally, outdoor air temperature data was gathered from the database of the nearest Weather Station from the Museum ID: ITERRASS3, located at 300m from the building at 2°00´48´´E, 41°33´59´´N and 307 masl. The information was collected in 20 min intervals.

The data were collected in 3 different periods but with the aim to make a comparable analysis, 1 day from each period with similar climatic conditions has been chosen, June 29th, July 1st and July 9th. All these days had clear sky conditions, with mean temperatures and SR of 28.8ºC, 360 W/m2; 28.6ºC, 330 W/m2; and 27.5ºC and 332 W/m2.

Results and discussion: Roof.

Figure 2 shows the results of the radiation heat flux data on the opaque surface (a) and glazed surface (b). Regarding to the results for opaque surface, it shows a SR curve with no interruptions, which reflected 0% obstructions, and completely clear sky conditions throughout the whole day. This radiation appears at 04:30h, it rises until its peak 1000 W/m^2 at 12:00h, and then it starts to fall down until disappearing at 19:30h. In regards to the LW at night periods from 00:00 h to 04:30 h and 19:30 h to 24:00 h the roof is emitting a flux quite constant, -87 W/m^2. While the SR appears the heat losses start to rise up until reaching its peak -192 W/m^2, around the same time with the SR peak. After this, its heat losses diminishes until the SR disappears and comes back to its constant behaviour at night.

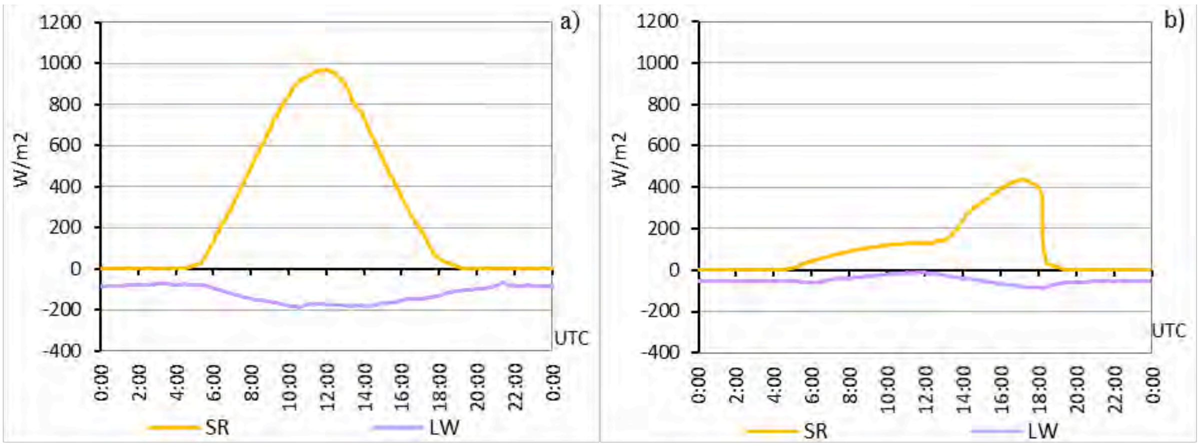

Figure 2. Solar and long wave radiation measured a) on the opaque surface and b) on the glass surface.

There is a relationship among the values of the SR and LW. However, this behaviour gets complicated on the glazed surface due to the roof geometry. The results on the glass surface, Figure 2b, show a SR curve with two different ascending slope. In the morning, the curve keeps a low ascending slope until midday, from 0 to 130 W/m^2. These values reveal the presence of the diffuse-reflect radiation, due to the fact that the glass panels oriented to the North avoid the penetration of the whole direct radiation in this period. After this, SR curve starts to rise with a higher slope until its peak 430 W/m^2, reflecting the incidence of the direct radiation. This behaviour can be observed in Figure 3b, which shows the incidence of the direct radiation only in the afternoon due to the building orientation, 19° to West.

With respect to the LW results, the heat flux is quite constant in the night time periods but with a lower value, -55 W/m^2, than the opaque surface. However in the daytime it displays a totally different behaviour. When solar radiation appears, specifically the diffuse-reflect component, heat losses decrease until -10 W/m^2, around midday. Then, this flux increases until its peak, -87 W/m^2. This responds to direct radiation incidence.

As mentioned, the relationship seen on the opaque part between the SR and LW is not the same in glazed surface results. This behaviour support that the heat losses do not only depend on the amount of the solar radiation received, but also on the heat exchange with its environment. In reference to this, the portion of sky seen by the glass is lower than the one seen by the opaque surface, 55-75% respectively, in terms of Sky View Factor (SVF). Furthermore, the portion of opaque surface seen by the glass has great influence on its heat losses performance due to the high amount of heat flux emitted by the opaque surface, as consequence of the high temperatures it reaches.

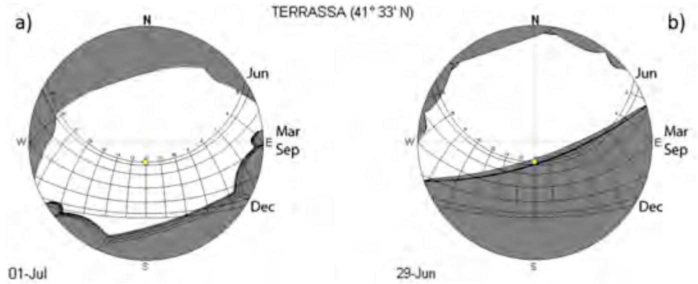

Figure 3. Obstructions of the sun paths in a stereographic projection from the same point of the pyranometer location on the opaque (a) and glass (b) surface. Graphics obtained by Heliodon (Beckers et al, 2003).

In order to analyse the whole heat radiation exchange, the exterior glass and opaque surface temperatures had been measured, Figure 4. At night time periods, these temperatures clearly only depend on heat losses by LW. This is reflected in the temperatures of both surfaces, which keep under the outdoor air temperature due to the high levels of LW emitted to the sky. Moreover, these results shows the influence of the lesser portion of sky seen by the glass compared to opaque part over its surface temperature, which impacts in an average of 2°C higher.

In daytime period, the temperature performance of these two surfaces are conditioned by both radiations: SR and LW. In regards to the opaque part results, these values show a behaviour quite corresponding to their radiation exchange, Figure 2a. In the same way, the results of glass surface temperature show the same pattern seen in the measurements of SR, a curve with two ascending slopes. Nevertheless, these two slopes do not have the large difference seen on radiation results, Figure 2b. With the purpose to analyse this behaviour, it has divided daytime in two periods, morning and afternoon. The average of SR received in the afternoon period is 3 times (255 W/m^2) higher than the one received in the morning (85 W/m^2). Meanwhile the average difference between surface and air temperature, comparing the same periods is 2.5 times, (5°C to 2°C). This behaviour responds to the scarcity of net LW flux emitted in the morning period, which impact in a higher temperature, and transparency of glass to SW.

Regarding the interior surface temperatures results, Figure 4b, the maximum value on both surfaces is around 17:00h. In the case of the opaque surface, it shows a delay of 5 hours and a reduction of 20°C, between the exterior and interior maximum. Meanwhile, in the glass part, the transmission occurs almost immediately, and it displays an increase of its temperature of 7°C. Moreover, the peak on the glass surface temperature is 10°C higher than the one of the opaque part.

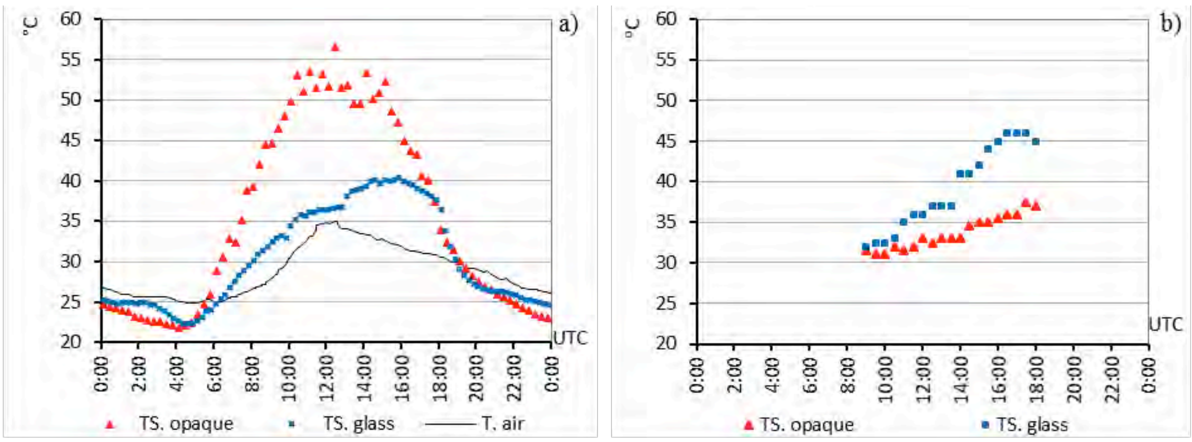

Figure 4. Glass and Opaque Surface temperatures a) exterior and b) interior

Results and discussion: Indoor.

Due to the air velocity measurements obtained (<0.4 m/s), the mean radiant temperature values are considered the same than the globe temperature values (Thorsson et al, 2007). Also, according to these air velocity values the operative temperature is equal to the globe temperature (ASHRAE, 2001).

Figure 5a, shows the indoor results of the air temperature (Tai) and the mean radiant temperature (Tmrt). Neither of these two parameters go under 30°C and their maximums are around 40°C. The indoor temperatures are higher than the outdoor air near the whole day. The average difference between inside and outside is 5°C. Moreover, Tmrt and Tai have the same behaviour and almost the same values in the entire period measured; the highest difference is in their peak time. Figure 5b displays the difference between the Tmrt and Tai (ΔTmrt-Tai). It is observed the range of difference goes from -0.4°C, very constant in night periods, to 1.53°C, in the peak time. Their maximums are around 17:00h, which coincide with the interior temperatures peak of the glass and opaque surfaces, Figure 4b. This reflect the large influence of these surfaces over Tmrt and the influence of this over Tai.

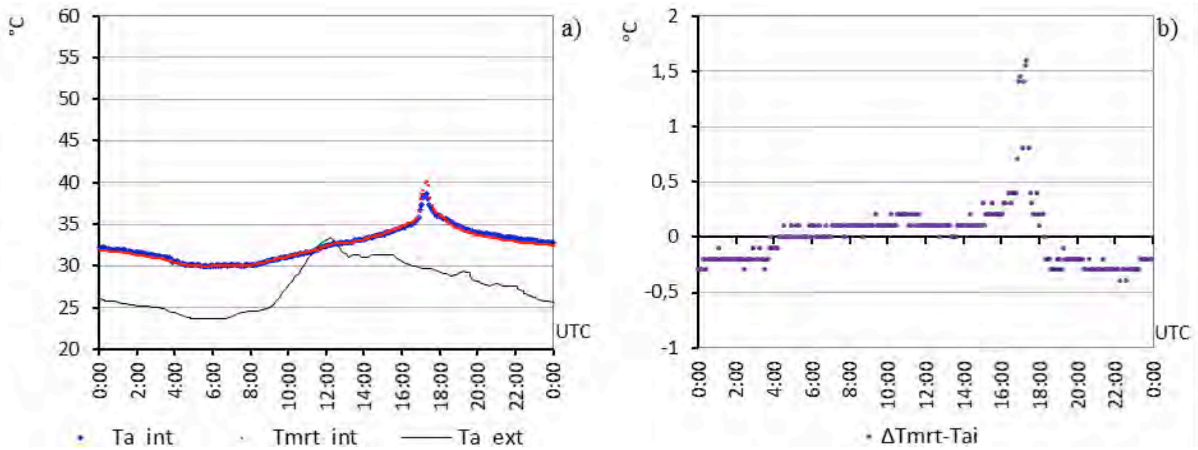

Figure 5. Indoor air temperature and mean radiant indoor temperature (a), and Difference between mean radiant temperature and air temperature (b)

In order to determine the independent impact of the roof surfaces over the interior ambient, it has been calculated the influence of surrounding surfaces over Tmrt. This parameter was calculated based on measured values of the envelope surface temperatures, and their positions respect to the chosen point, shape factor (SF) (Kabre, 2010) obtained from the software Heliodon (Beckers et al, 2003). Equation (1) was used for this purpose:

$$T_{mrt}^4 = \sum_{i=1} T_{si}^4 \, . \, F_{pi} \qquad (1)$$

Where, T_{mrt} = mean radiant temperature, in K, T_{si} temperature of surface N, in K, F_{pi} angle factor between a point and a surface N. If we refer to the specific case analysed, then the equation can be written as:

$$T_{mrt}^4 = T_{s.op}^4 \, .F_{p.op} + T_{s.g}^4 \, .F_{p.g} + T_{s.w}^4 \, .F_{p.w} + T_{s.f}^4 \, .F_{p.f} \qquad (2)$$

It has simplified the impact of the all surrounding surfaces to one interior point, in 4 surfaces, op = opaque surface, g = glass surface, w = walls, f = floor. Regarding the radiant temperatures, according to the thermal images, Figure 6, the floor and walls have almost the same values than Tai measured, while roof surfaces have higher temperatures. Thus, only roof surfaces are considered in the analysis of the influence over Tmrt. To obtain Ts.g.

and Ts.op. it has been averaged the 9 different points measured over each part. With respect to shape factor parameter, it has been simulated the angle factor between these 4 surfaces and one interior point with the same location of the globe thermometer.

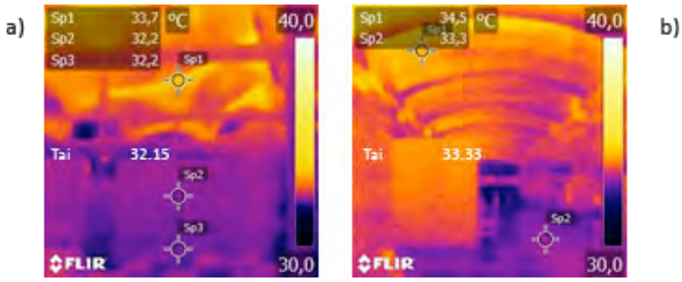

Figure 6 . Interior thermal image 10h00 UTC (a), and 14h00 UTC (b).

Figure 7 shows the difference between the global mean radiant temperature and the mean air temperature (ΔTmrt-Tai), depending on the different values of surrounding temperatures and their shape factors. In the axis X, the range of the surfaces shape factor values, from 0 to 0.5, since 0.5 SF will be the maximum angle factor between the roof and the point analysed. In the axis Y, the values of the difference between surface temperature and air temperature (ΔTs - Tai).

It has been analysed the influence of the Ts.g. and Ts.op. on Tmrt at two different heights: P1: 2.4 m which simulate the same location of globe thermometer, and P2: 4.8 m, a point located in a second floor. The analysis corresponds to temperature peak time, 17:00 h.

According to these results, the glass part has a higher influence over ΔTmrt-Tai than the opaque part on both points analysed. On P1, the influence of the glazed part is 0.84°C and the opaque part is 0.56°C, 60–40% respectively. Meanwhile on P2, the influence, in the same order, are 1.09°C and 0.57°C, 66-34% respectively. It can be observed that when the analysed point gets closer to the roof, the influence of both surfaces over ΔTmrt-Tai becomes higher. However the glass part increases its influence 0.25°C, while the opaque part 0.01°C.

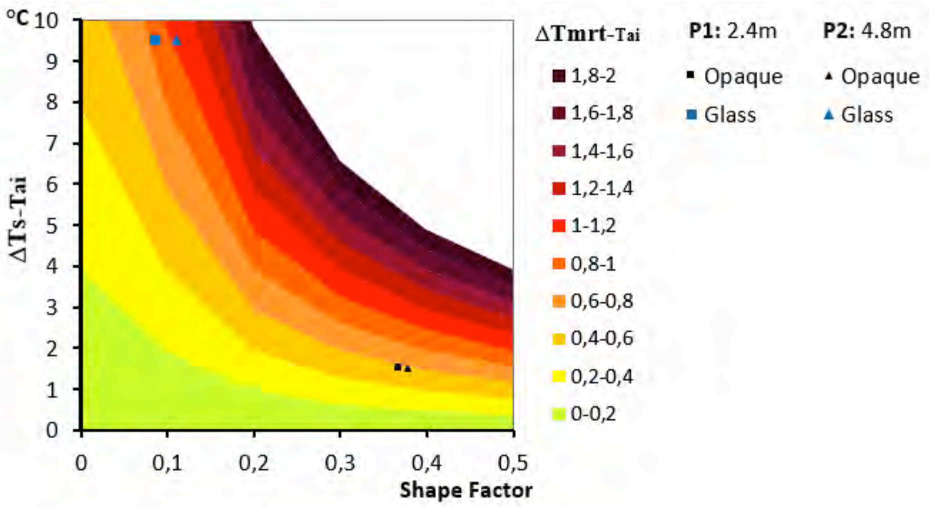

Figure 7. Shape Factor and ΔTs-Ta influence of the surrounding surfaces over Tmrt

Conclusions.

This research approach the analysis of the rehabilitated industrial building interior ambient conditions, focusing in the envelope radiative performance and its impact on the users.

The parameters analysed in this study, Tai and Tmrt, have a strong dependency on the roof thermal behaviour. Considering the whole building volume the highest heat exchange is with the roof surfaces, while the heat flux with the walls and the floor is negligible. In this sense, this analysis supports that the glass surface has the highest repercussion, between the all surfaces of the envelope, over Tmrt. The glass impact represents the 60-66% of the entire long wave radiation flux. This behaviour responds to the high temperatures reached by this surface, 47°C (maximum) although this surface is oriented to the North. These temperatures are determined by the constant action of the diffuse component throughout the whole day, and particularly to the heat radiation emitted by the opaque part, which diminishes the heat losses of this surface.

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Design to Thrive

Development of simulation program that helps designers find potential overheating in houses

Yuko Tsukiyama

Architectural Technology Dept., Asahi Kasei Homes Corporation, Tokyo, Japan,
S-TEC Building 24-1, Nishi-shinjyuku 1-chome, Shinjyuku-ku, Tokyo 160-8345, Japan
tsukiyama.yb@gmail.com

Abstract: This study aimed to reveal the effect of solar radiation heat through windows and provided a simulation program to mitigate overheating in houses. First, we measured the amount acquisition of solar radiation heat through windows using a full-scale model house to reveal the effect of room direction. Second, we identified cases wherein house occupants felt uncomfortable because of overheating during summer and collected their house plans to check the typical feature of overheating. Using these existing house plans we determined the relation between the amount of solar radiation trough windows and occupants' uncomfortableness. Third, we adjusted the parameters in the analysis to calculate the solar radiation heat, examined the results of the simulation and then set the threshold to determine whether the room had the possibility of overheating in summer. Finally, we developed a simulation program that alerts designers of overheating at the stage of planning a house and it could help designers choose the most suitable solution for the overheating easily.

Keywords: overheating during summer, simulation program, experimental measurement, analysis of questionnaire

Introduction

Overheating, which is caused by both global warming and high insulation, has become a serious problem in recent years. In Japan, the main cause of overheating originates from solar radiation heat through windows, the size of which is relatively large in typical Japanese houses. The best way to confirm whether a room would be overheated is to calculate the room temperature using technical thermal simulation program. However, using such a simulation program is difficult for designers because of its complexity. When we simulate an indoor thermal environment, we must consider various effects such as heat capacity of the structure and absorption of solar heat into walls. Moreover, evaluating the phenomenon of overheating in detail is time consuming.

In this study, we aimed to provide a solution for mitigating overheating in houses more easily for designers. As only a few studies have been conducted on solar radiation heat through windows and overheating of houses, we constructed an experimental house to measure the relation between the acquisition of solar radiation heat thorough windows and the thermal indoor environment and analysed questionnaires about comfort during summer to develop a simulation program for overheating.

We already developed an original simulation program for indoor environments, called ARIOS. ARIOS can calculate and display the effects of the estimated sunshine hours on the floor and indoor natural ventilation routes (Figure 1). We considered adding the prediction function for the possibility of overheating to this program. The existing simulation program uses the Expanded AMeDAS Weather Data. Therefore, the new simulation for overheating should use the same weather data for convenience in calculating.

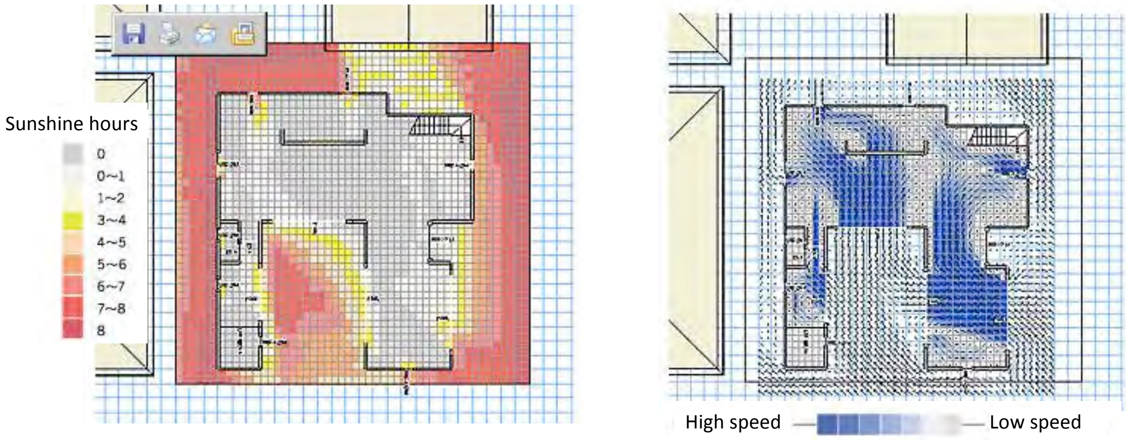

Figure 1. Display example of ARIOS: Diagram on the left represents the sunshine hours and that on the right illustrates the natural ventilation routes

Taking into consideration the factors mentioned above, we decided to use the acquisition of solar radiation heat to predict the possibility of overheating in rooms.

Measurements of a full-scale model house

Experimental methodology

The experimental house was constructed in Itabash-ku, Tokyo, Japan. The test rooms were located on the second floor to avoid sunlight blockage by nearby buildings. Two symmetrical rooms were used with openings in either the south and east or the south and west walls to compare the indoor thermal environment through different solar directions and their effects. Each room had a floor space of 13.4 m^2, a ceiling height of 2.4 m and openings consisting of double-glazed low-e glass with an aluminium sash. The main structure comprised a steel frame with autoclaved, aerated light weight concrete panels. Wall insulation consisted of high-performance phenolic foam 25 mm in thickness in the exterior walls, rock wool 100 mm in thickness in the ceiling chamber and rock wool 55 mm in thickness in the party walls. These features were the standard insulation used in Japan in 2004. All measurements were performed during the summer of 2004 using T-type thermocouples, globe thermometers and pyranometers placed approximately 1 m above the floor level in the locations shown in Figures 2 and 3.

As shown in Table 1, the five experimental modes were as follows: Mode-1 with solar radiation through all windows without (Mode-1a) and with (Mode-1b) air-conditioning (a/c) and Mode-2 with solar radiation heat through the southern window only without (Mode-2a) and with (Mode-2b) outer solar shading devices as well as changing the glass type to reduce heat from the sun (Mode-2c).

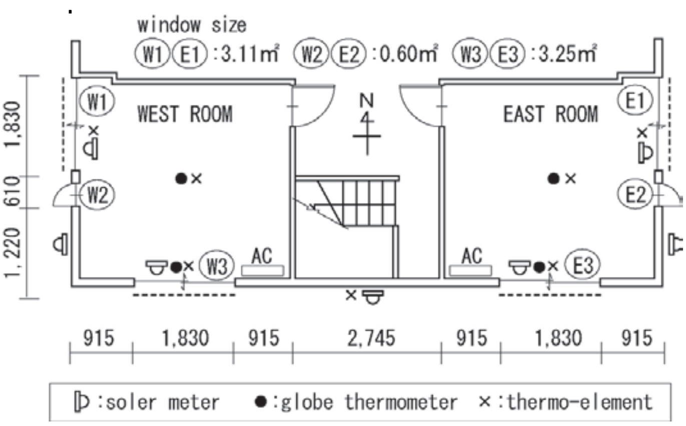

Figure 2. Floor plan and measurement point

Figure 3. West room interior

Mode	Type of glass		Solar shading		Air conditioning	Measurement day
	South	East or West	South	East or West		
Mode-1a	Double glazed low-e	Double glazed low-e	without	without	—	2nd-7th/July
Mode-1b	Double glazed low-e	Double glazed low-e	without	without	ON at 27 °C	11th-19th/August
Mode-2a	Double glazed low-e	—	without	—	—	7th-13th/July
Mode-2b	Double glazed low-e	—	with	—	—	14th-20th/July
Mode-2c	Double glazed low-e (to reduce heat from the sun)	—	without	—	—	21st-29th/July

Table 1. Experimental modes

Experimental results

Figure 4 shows the air temperature 1 m above the floor in the middle of the room (hereinafter called 'room temperature') and the inside vertical insolation and Table 2 presents the integrated value of insolation per typical day in Mode-1a (no a/c).

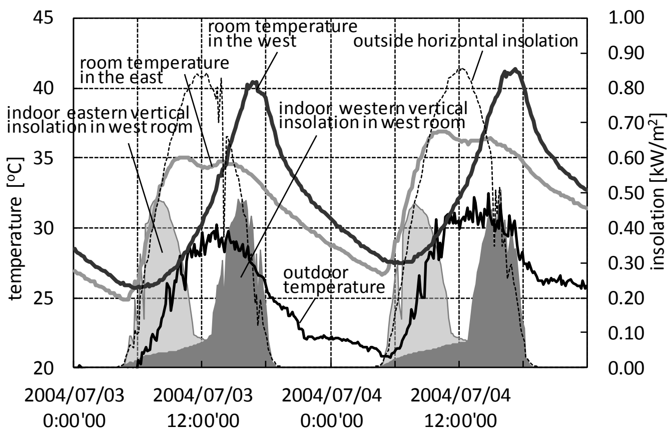

Figure 4. Temperature and insolation patterns in Mode-1a

Table 2. Integrated value of insolation per typical day in Mode-1a

Outdoor [MJ/m^2]				Indoor [MJ/m^2]	
Horizontal	Vertical			East	West
	South	East	West		
24.61	8.39	12.35	11.23	39.34	39.37

In Mode-1a (no a/c), room temperature in the east increased rapidly with the increase of outdoor temperature, reached a peak temperature of 35 °C at 10:00, remained stable at a high level until 13:40 and thereafter began to decrease gradually. In contrast, room temperature in the west showed a bell-shaped curve, and it reached the peak room temperature of 40.4 °C at 16:40. As shown in Table 2, the integrated values of the inside vertical insolation of both rooms were almost the same. Therefore, the difference in room temperature between the room in the east and that in the west was caused by the onset of the solar radiation heat through the windows in each room. The room in the east received solar radiation heat through the windows during the mid-morning hours when the room and outdoor temperatures had not increased yet, whereas the room in the west gained the solar radiation heat through the windows in the afternoon when the room temperature had already increased because of the increased outdoor temperature and heat of transmission through the walls and the roof. Therefore, we should consider the effects of heat gain which the room has already received in addition to solar radiation through windows in examining the room temperature in rooms facing west.

Figure 5 shows the room temperature and the inside vertical insolation, and Figure 6 illustrates the vertical temperature distribution of a typical day in Mode-1b (with a/c). As shown in Figure 5, the room temperature in both the rooms was stable at the a/c setting of 26 °C throughout the measurements. Figure 6 indicates the different trends of the vertical temperature distribution. In particular, the temperature close to the ceiling and the floor of the room in the west at 16:00 was over 30 °C, thus making difficult to maintain a comfortable indoor environment in the afternoon even though a/c was turned on.

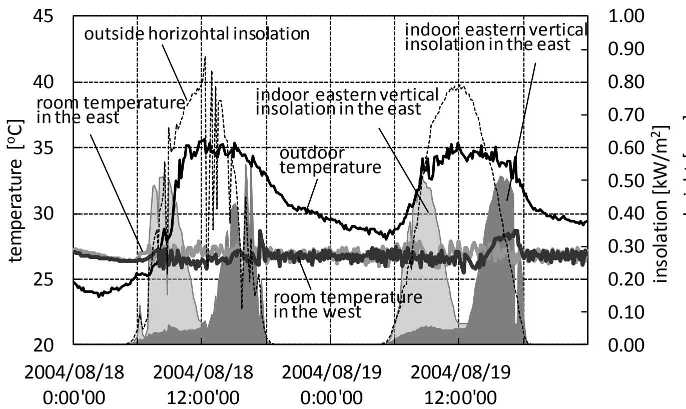

Figure 5. Temperature and Insolation patterns in Mode-1

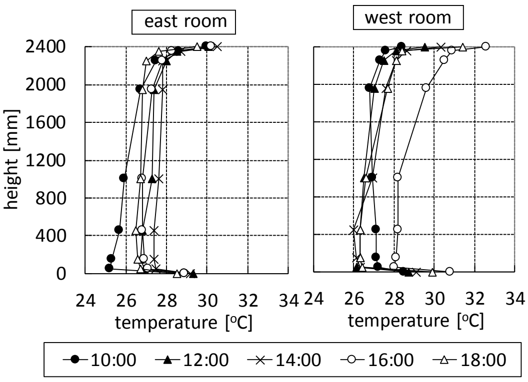

Figure 6. Vertical temperature distribution in Mode-1b

The solar radiation heat acquisition ratio calculated by the results of Mode-2 (southern window only) and the outside view of the opening are illustrated in Figures 7 and 8, respectively. In Figure 8, the image on the right shows the opening covered with an outer solar shading device. This removable outer shading device is made of polyester finished with resin. The solar radiation heat acquisition ratio was estimated as a relative value of the outside vertical insolation on the south wall by the amount of indoor vertical insolation in a typical day in each experimental mode, and it was similar to that of the outside environment.

Then calculated solar radiation heat acquisition ratios in Mode-2a (double-glazed low-e glass), Mode-2b (double-glazed low-e glass with outer solar shading device) and Mode-2c (double-glazed low-e glass that reduces heat from the sun) were approximately 40%, 25% and 30% respectively. This result reveals that the most effective solar shading method is installing an outer shading device. Each design value was 62%, 18% and 40% respectively, and the calculated value of glass was smaller than that of design value due to the high altitude of the sun in the measurement term.

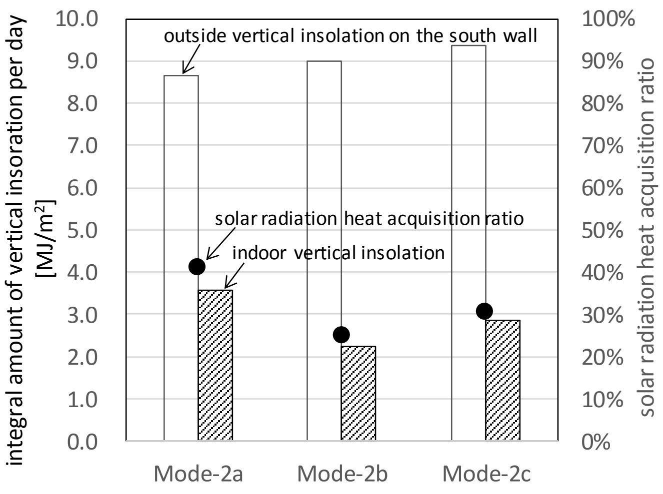

Figure 7. Solar radiation heat ratio in Mode-2

Figure 8. Outside view of the southern window (right: with outer solar shading device

Analysis of existing houses and the threshold setting

Extracting case studies on overheating

We identified cases wherein house occupants felt uncomfortable because of overheating during summer by examining the results of general questionnaires conducted by us regularly. The target subjects of the questionnaires were those who lived in the houses we built for more than one year. We extracted 87 case studies. Examples of the answers about overheating were ‘My room on the first floor is too hot during summer’, ‘My room facing west gains too much solar heat’. Simultaneously, we collected the subjects’ floor plans. We found similar features that could likely cause overheating such as large windows or no shading devices. Furthermore, the occupants revealed that small rooms, such as the kitchen or toilet, with windows on the western wall were too hot. To investigate the possibility of overheating of these houses, we conducted a simulation on the acquisition of solar radiation heat using the original simulation program called ACHIEVE which was developed based on the SMASH multizone dynamic thermal simulation program.

Customisation of parameters

The simulation aimed to determine which houses were likely to suffer from overheating in summer. Thus, we used a different approach from the usual thermal simulation: we customised the parameters. First, we redefined ‘simulation period’ to ‘July to September’ to be more specific. Furthermore, we extracted only the dates with a horizontal quantity of total solar radiation per day of over 14 MJ/m^2, and these dates were predicted sunny days.

Second, we calculated the outside temperature to adjust the calculated acquisition of solar radiation heat of the room facing west. Because we confirmed that the occupants were prone to feeling uncomfortable in the room facing west even if the acquisition of solar radiation heat through windows in the room facing west was similar to that in the room facing east in both the measurements results and the questionnaires. In particular, we added ‘outdoor temperature / 25 °C’ to the outdoor temperature when the outdoor temperature had been over 25 °C. By adjustment of this parameter, we could evaluate the effect of the direction.

Third, the solar radiation heat acquisition ratio of glass was specified in more detail. This ratio of glass could vary depending on the altitude of the sun but we used a fixed value for the thermal simulation program because of convenience of calculation. We set the different solar radiation heat acquisition ratios of glass at different solar altitudes to accurately calculate the acquisition of solar radiation heat through windows.

Results of the simulation

Figure 9 shows the results of the simulation of the 87 existing houses using the abovementioned customisation of parameters. The simulation used weather data of the place where the existing houses were built. The calculated acquisition of solar radiation heat is called the comparable acquisition of solar radiation heat (CASRH) to distinguish the value from the physical quantity of solar radiation heat. We set the unit of the calculated acquisition of solar radiation heat of the rooms to [kJ/m^2·mat]. Mat denotes the size of 1 tatami mat of 1.67 m^2, which is the standard unit to describe the size of rooms in Japanese houses. We chose this unit because it enabled us to compare the possibility of overheating in rooms with different sizes such as living room, kitchen and toilet.

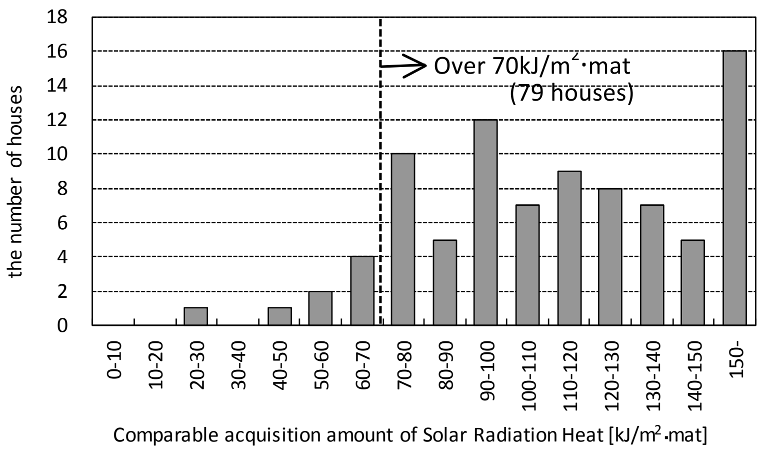

Figure 9. Results of the simulation of existing houses

If the threshold for judging overheating were set to too high/low figures, we could overlook the possibility of overheated houses or wrongly pick up rooms of non-overheated. To achieve 90% coverage, we temporarily set the optimum value for the threshold at 70 [kJ/m^2·mat] after trying several simulations.

Subsequently, we simulated the CASRH of three different solar shading devices to confirm the validity of the threshold using the weather data in Tokyo wherein most of the houses we provided were built. The simulation utilised the plan based on a typical Japanese room of 13.4 m^2 (eight mats) with a large window of 3.25 m^2 in the south wall and a small window of 0.6 m^2 in the west; both windows were made of double-glazed low-e glass in the model plan. Figure 10 illustrates the model plan and the results. The chosen solar shading devices were as follows: Mode-A with a window in the west changed to a double-glazed low-e glass to reduce heat from the sun, Mode-B with an outer solar shading device installed in the opening in the west and Mode-C with overhanging eaves over the southern window. We chose these solar shading devices because they were the most basic methods to reduce the acquisition of solar radiation heat against each direction.

The calculated CASRH values were Mode-A 69 [kJ/m^2·mat], Mode-B 59 [kJ/m^2·mat] and Mode-C 43 [kJ/m^2·mat], which were all under the threshold 70 [kJ/m^2·mat]. Thus, applying a solar shading device correctly could contribute to reducing CASRH to the level of below 70 [kJ/m^2·mat].

Considering these analysis, we set the threshold to 70 [kJ/m^2·mat] at this point.

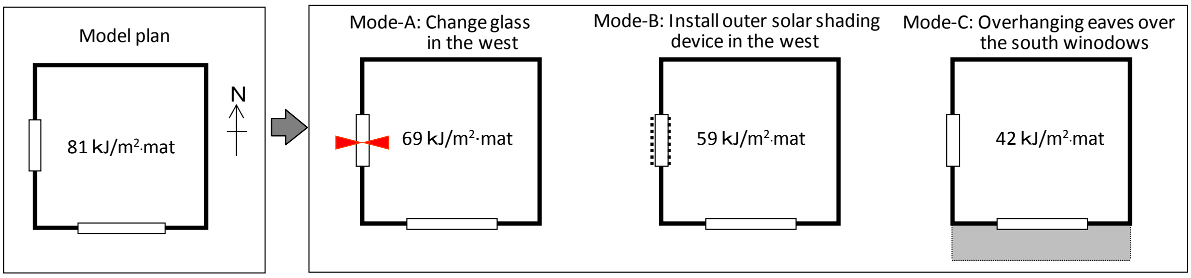

Figure 10. Results of the simulation of solar shading devices

Display of the simulation results

Figure 11 illustrates an example of the results alerting the possibility of overheating. The diagram on the left shows the result without countermeasures against overheating and that on the right shows the results after the plan is modified to prevent overheating.

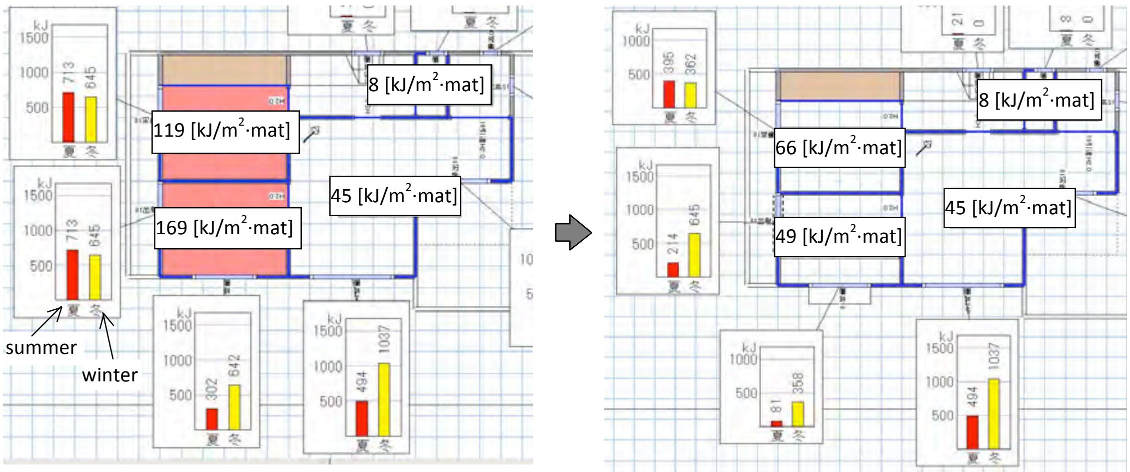

Figure 11. Illustration of an example of the results alerting the possibility of overheating (left: without countermeasures, right: with various solar shading devices)

Similar to the ARIOS simulation program, designers input the floor plan, choose the weather data of the place where the house was built and press the calculate button to simulate CASRH. The process takes only a few minutes. If the calculated CASRH is over the threshold of 70 [kJ/m^2·mat], the room is displayed in red and the simulated acquisition of the solar radiation heat through windows is marked at each window. Consequently, designers can easily find the rooms with the possibility of overheating in the stage of planning a house and provide an effective solar shading strategy for the window that gains much acquisition of solar radiation heat. In the illustration, we provide the acquisition of solar radiation heat through windows in winter because it varies with the season or method of solar shading. For example, a southern window with overhang eaves prevents much acquisition of solar radiation heat in summer, but it can gain abundant acquisition of solar radiation heat, which is effective in reducing heating energy in winter. Through the presentation of the acquisition of solar radiation heat in both summer and winter, designers can easily choose the most suitable solution for any situation.

Conclusion

To develop a simulation program that alerts designers of overheating, we conducted measurements using a full-scale model house and analysed existing houses that seemed to suffer from overheating. The measurements revealed that although the acquisition of solar radiation heat through windows was almost the same in the houses, the room temperatures in the rooms in the east and west were different. Moreover, the measurements showed the influence of solar altitude on the solar radiation heat acquisition ratio of glass. By analysing questionnaire and the floor plans of the existing houses we provided, we adjusted the parameters by which the threshold could identify the rooms with a possibility of overheating. Finally, we developed a simulation program that could help designers find potential overheating in houses.

In the future, the threshold will have to be adjusted if the thermal performance of a house is changed. This adjustment can be conducted easily using the proposed method.

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Minimising Overheating in Passive and Low Energy Buildings Using Kriging-based inverse modelling techniques

Michael Wood[1], Matthew Eames[1] and Daniel Fosas[2]

[1] College of Engineering, Mathematics and Physical Science, University of Exeter, Exeter, UK
[2] Department of Architecture and Civil Engineering, University of Bath, UK.

Abstract: Preventing summertime overheating within passive buildings is important for the comfort of the occupants. The likelihood that a building will overheat depends on several factors, including the form of the building, the percentage glazing and the building's thermal mass and insulation. Furthermore, the amount of overheating depends on the criteria we use to measure it. We investigate the CIBSE TM52 overheating criteria and look at how they are affected by changes in the design of a *PassivHaus* style building. We calculate the percentage of possible buildings that pass each of the three CIBSE criteria using the *Gaussian process regression*-based *efficient global inversion* (EGI) technique. Our work is divided into two stages. First, we look at the sensitivity of the overheating criteria to the design (*i.e.* examining the building parameters that have the greatest effect on the overheating criteria). Second, we calculate the percentage of all possible building designs that meet these criteria using the EGI technique. This method provides an estimation of whether a building design will meet a criterion. This *surrogate modelling* method can be very accurate because the EGI technique 'tunes' the Gaussian process regression model to determine whether variables exceed a threshold. We explore the overheating criteria for 60,000 potential building designs. Our findings show that the relative glazed area has the greatest influence on the overheating criteria, whereas properties such as thermal mass and insulation have less effect than expected. Further work is needed to explore the effects on different building types in other climates.

Keywords: Overheating, Gaussian process, Inverse modelling, Design summer years

Introduction

To reduce the energy used by heating, many passive buildings are built with very low U-values. This minimises heat loss over the winter, but it can lead to overheating during the summer months. Since the form of the building affects overheating the most, buildings must be tested for problems before they are built (Jenkins et al., 2012). This means that we need to make use of computer simulations and simulated weather conditions so that design decisions can be made. Because of the need for computers in the design process, software simulations of buildings have a large influence on the building design.

The metrics used to measure overheating and the way that we measure overheating will influence the types of buildings that we design in the future. Our aim is to look at how *PassivHaus* style residential buildings might be affected by both the weather files and the parameters used to design them.

There are a potentially infinite number of building design parameters that can be adjusted, but some have been shown to be more important than others. These include the use (and size) of brise soleil, the amount of glazing, the orientation of the building and the relative amount of thermal mass (Eames et al., 2015; Banfill et al., 2012).

The weather files used for the dry in the simulation will also influence the building design. In the UK, design summer years (DSY) are used to test for overheating. In our work, we use the new CIBSE DSYs (Eames, 2016). These DSYs comprise of 42 weather years – 3 for each of 14 locations across the UK. The DSYs at each location each contain a moderate, and two separate near-extreme heat wave events (DSY1). One represents a year with a short more intense heat wave event (DSY2) and the other with a longer heat wave event (DSY3). We examine the effect of these extremes on the relative number of available building designs for each weather year.

We explore the effect of varying five continuous building feature on the potential overheating of the building as judged be various overheating criteria. However, as the building parameters are continuous, there are a potentially infinite number of combinations. Even if the features are limited to 20 discrete values each, the total number of simulations required would be 3.2 million. Therefore, to make this problem more tractable, we use a Gaussian process regression model to emulate the values for two of the three CIBSE overheating criteria from CIBSE TM 52 (Nicol, 2016)[1]. We have used GP models because the can be tuned to be very accurate at distinguishing between thresholds in a model. For example, if we know that we want one of our criteria to be below 3%, then we can tune the model to accurately predict whether certain building designs will be above or below this value.

Methods

Building model

The building model that we will analyse is a simple mid-terrace residential building. We simulate the results of the building model using *EnergyPlus v8.4* (US Department of Energy 2017). The building is designed to meet the standards required by *PassivHaus* (Hopfe & McLeod, 2015) and is shown in Figure 1.

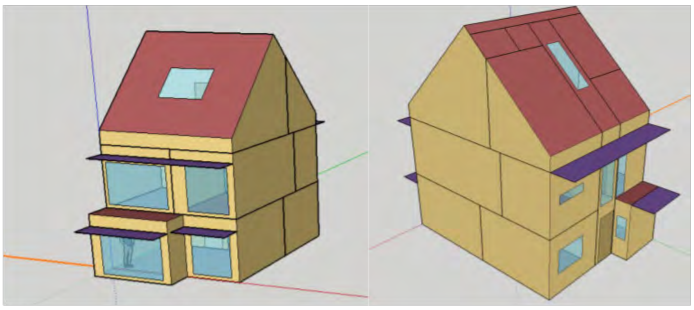


Figure 1: Building being modelled (maximum glazing and overhang shown)

The U-values for the building elements are shown in Table 1. The table also shows the glazing *g*-values, light transmission and the thickness of each of the elements used. We allow the glazed area, orientation, overhang distance, brick thickness, roof slab thickness and the position of the insulation to be varied. The maximum and minimum variables are shown in Table 2.

[1] We have not included CIBSE criterion 3 because we are not considering short temperature peaks.

Table 1: Thermal design of building

Variable	Value	Unit
U-Value Wall / Roof / Ground	0.10	$Wm^{-2}K^{-1}$
U-Value Door and $Window_{limit}$	0.85	$Wm^{-2}K^{-1}$
U-Value $Window_{real}$	0.76	$Wm^{-2}K^{-1}$
g-value	0.59	Ratio
Light Transmission	0.69	Ratio
Window layers (triple glazed)	5 / 12 / 4 / 12 / 5	mm / mm / mm / mm / mm

Table 2:Variables changed in the building model

Variable	Min	Max
Glazing area	2.6 m^2	26.0 m^2
Orientation (from North)	-90°	90°
Overhang distance (m)	0.1 m	0.9 m
Wall and roof thermal mass thickness (T_{thick})	100 mm	400 mm
Roof slab thickness	100 mm	400 mm
Relative size of internal to external wall leafs (R_{rel})	0.1	0.9

We use R_{rel} to calculate the relative thicknesses of the external (W_{ext}) and internal wall leafs (W_{int}) using the following equations:

$W_{\text{ext}} = T_{\text{thick}} \times R_{\text{rel}}$ and $W_{\text{int}} = (1 - T_{\text{thick}}) \times R_{\text{rel}}$

CIBSE TM52 Criteria

To test the buildings for overheating, we have used the new CIBSE design summer years (DSYs) for the UK (Eames, 2016). We used the DSY1, DSY2 and DSY3 weather files for Plymouth, London and Manchester and used them to calculate CIBSE 1 and 2 criteria (Nicol, 2016). CIBSE criterion 1 measures the number of hours where the internal operative temperature is above the maximum acceptable temperature (H_e) and CIBSE criterion 2 measures the *maximum daily weighted exceedance* (W_e). Both criteria are calculated based on a variable known as ΔT.

ΔT measures the exceedance of the maximum acceptable internal temperature. It is calculated on every time step of the simulation and is related to the operative temperature, T_{op}, that is in turn based on the air temperature, T_a, and the mean radiant temperature, T_r:

$\Delta T = T_{op} - T_{max}$ Where $T_{op} = \frac{T_a - T_r}{2}$

The maximum acceptable temperature T_{max} is dependent on the *running mean* temperature, T_{rm}:

$T_{max} = 0.33T_{rm} + 21.8$ (where T_{rm} is defined as: $T_{rm} = (1-\alpha)T_{od-1} + \alpha T_{rm-1}$)

Where T_{od-1} is the outdoor daily mean temperature for the previous day, T_{rm-1} is the running mean temperature for the previous day and α is an empirically derived coefficient (typically 0.8). These equations can be used to derive ΔT for each time step.

- **CIBSE Criteria 1: Hours of exceedance (H_e)** - Criterion 1 sets a limit on the number of hours where ΔT is greater than 1 between 1st May and 30th September. This is the number *hours of exceedance* and provides measure of the *duration* of the overheating periods. The criterion is expressed as a percentage of the occupied hours. To pass criterion 1, the percentage of occupied hours where ΔT is greater than 1, should be 3% or less.

- **CIBSE Criteria 2: Daily weighted exceedance (W_e) -** Where criterion 1 measures the duration of overheating, criterion 2 measures the relative *severity* of overheating events. The daily weighted exceedance, W_e, measures the daily overheating severity: $W_e = \sum_{h=1}^{24} \Delta T_h$ where h is the hours of the day. This criterion is satisfied if W_e is less than 6 for all days during the year.

Seeing the building as a mathematical function

The building model can be viewed as a function. This is because the computer model takes input variables (a vector of inputs, **x**, which describe the design of the building) and converts them into two outputs, CIBSE criterion 1 and CIBSE criterion 2. We can represent these outputs as $f_1(\boldsymbol{x})$ and $f_2(\boldsymbol{x})$. Note that the choice of weather file also affects the output (Figure 2).

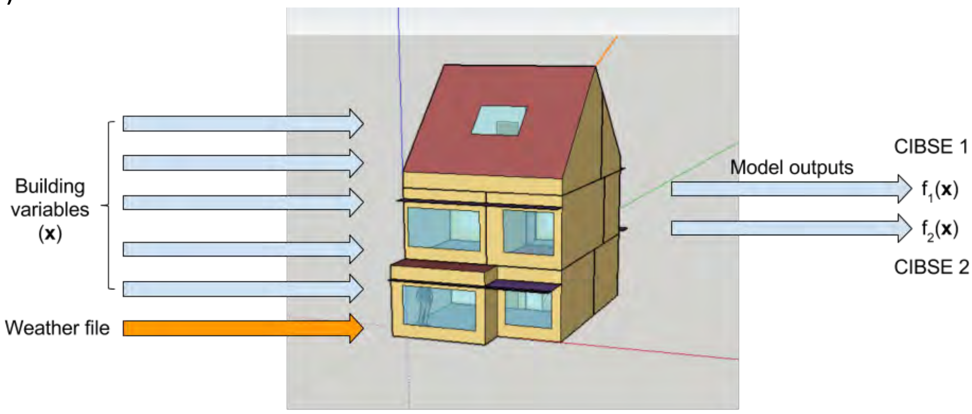


Figure 2: Representing the *EnergyPlus* building model as a function

Exploring the outputs of the building model using Gaussian process and Efficient Global Inversion

Since there is no analytic way to link $\boldsymbol{x}$ and $f(\boldsymbol{x})$, we need run the building simulator each time we want to obtain its output $f(\boldsymbol{x})$. It is possible to use the simulator alone for this, but if we want to explore a design space with more than 1 or 2 input variables, this quickly becomes a very large problem (see Bellman's curse of dimensions (Bellman 1957)). One solution to this problem is to use a surrogate model for the building model, $\hat{f}(\boldsymbol{x})$. Many different types of surrogate model can be used, but we use a Gaussian Process (GP) regression model.

We use GP regression in our model for two reasons. First, GP models allow us to explore a large sample of possible designs in a reasonable amount of time. The second is that GP regression models can be 'tuned' using a method called Efficient Global Inversion (Chevalier et al. 2014) to distinguish thresholds in the model with a relatively small number of training simulations. However, we first show how we create a regression model from the building.

GP regression has certain advantages over other regression methods. One of the nice properties of this method is that it requires relatively few training samples to provide good emulation, as little as 10 – 15 samples per input parameter (Loeppky et al., 2009) .

Efficient Global Inversion (EGI) iteratively improves the surrogate model and improves its ability to estimate a *threshold* within the model. This allow us to accurately predict whether a design will exceed an output value. In our case, we want to know whether the CIBSE criteria will be exceeded.

This is useful for our experiment in that we can build emulators with good accuracy at predicting whether the model has failed the criteria for the hours of exceedance (threshold at $H_e = 3\%$) or the daily weighted hours of exceedance (threshold at $W_e = 6$ degrees).

To improve the emulator at each threshold, EGI uses a three-step iterative process:

1. Create a surrogate model $\hat{f}(\boldsymbol{x})$ for the original building model $f(\boldsymbol{x})$
2. Predict the next sample $(\boldsymbol{x}_{n+1})$ that will improve the threshold estimate the most
3. Run the simulator at point $\boldsymbol{x}_{n+1}$ and return to step 1.

The surrogate model is created using a training set of inputs $\boldsymbol{D}$ (where $\boldsymbol{D} \in x$), which is created using a Latin hypercube design (Franco et al., 2011). This set of inputs are fed into the building simulator one at a time. This produces the *response* data $f(\boldsymbol{D})$. The input data and the response data are then used to *train* the surrogate model.

GP models are different from most linear regression methods as the outputs is represented as a multivariate Gaussian process:

$$\hat{f}(\boldsymbol{x}) \sim \mathrm{GP}(m(\boldsymbol{x}), v(\boldsymbol{x}, \boldsymbol{x}'))$$

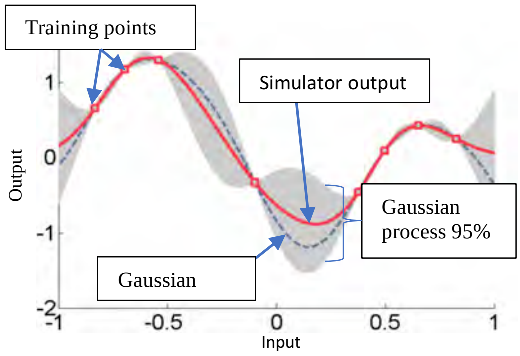


Figure 3: Gaussian process function and example realisation in one dimension

where $m(\boldsymbol{x})$ is the mean function and $v(\boldsymbol{x}, \boldsymbol{x}')$ is the variance function.

Although that output of the Gaussian process is essentially random Gaussian noise (with a mean of $m(\boldsymbol{x})$ and a variance of $v(\boldsymbol{x}, \boldsymbol{x}')$), this doesn't mean that we think the original simulator output is random. Instead, we are using the Gaussian process to allow us to express uncertainty in the output as demonstrated in Figure 3 above. The mean and variance functions of the Gaussian process model are estimated using a training set (□ shown in Figure 3). Standard functions govern the mean and variance. However, these functions require the tuning and estimation of hyper-parameters, who's derivation would be too lengthy to detail here. There interested reader is referred to *Gaussian Processes for Machine Learning* (Rasmussen & Williams 2006).

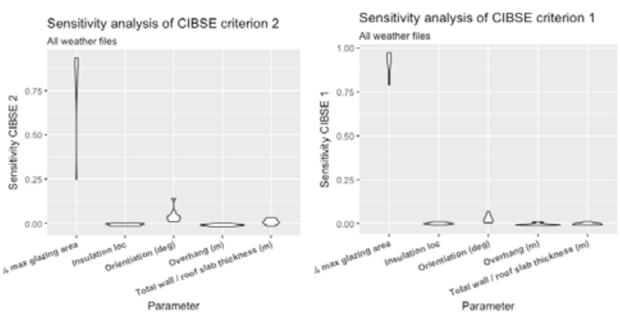
Results

Table 3 shows the percentage of buildings passing for both CIBSE criterion 1 and criterion 2 for each of the weather files tested.

Table 3: Proportion of emulated buildings passing the CIBSE criteria

Weather file	% passing CIBSE 1	% passing CIBSE 2	% passing both
London DSY1	49.8	5.4	5.4
London DSY2	86.5	66.0	66.0
London DSY3	43.6	0.4	0.4
Manchester DSY1	96.6	35.7	35.7
Manchester DSY2	90.9	27.2	27.2
Manchester DSY3	60.9	0.8	0.8
Plymouth DSY1	100.0	96.3	96.3
Plymouth DSY2	100.0	75.3	75.3
Plymouth DSY3	96.4	32.6	32.6

Figure 4: a) Sensitivity analysis of CIBSE 1 (left) of CIBSE 2 (right) for all weather files



The results of the sensitivity analysis show that the main first order effects on both CIBSE criterion 1 and CIBSE criterion 2 are the orientation and the % maximum glazing area. The analysis was conducted using the *sobol* function of the *sensitivity* package for *RStudio* (R Core Team, 2017; Sobol, 1993) . Figure 4 a) and Figure 4 b) shows a violin-plot of the sensitivities of the parameters across all the weather files tested. Figure 5 shows the compliant designs.

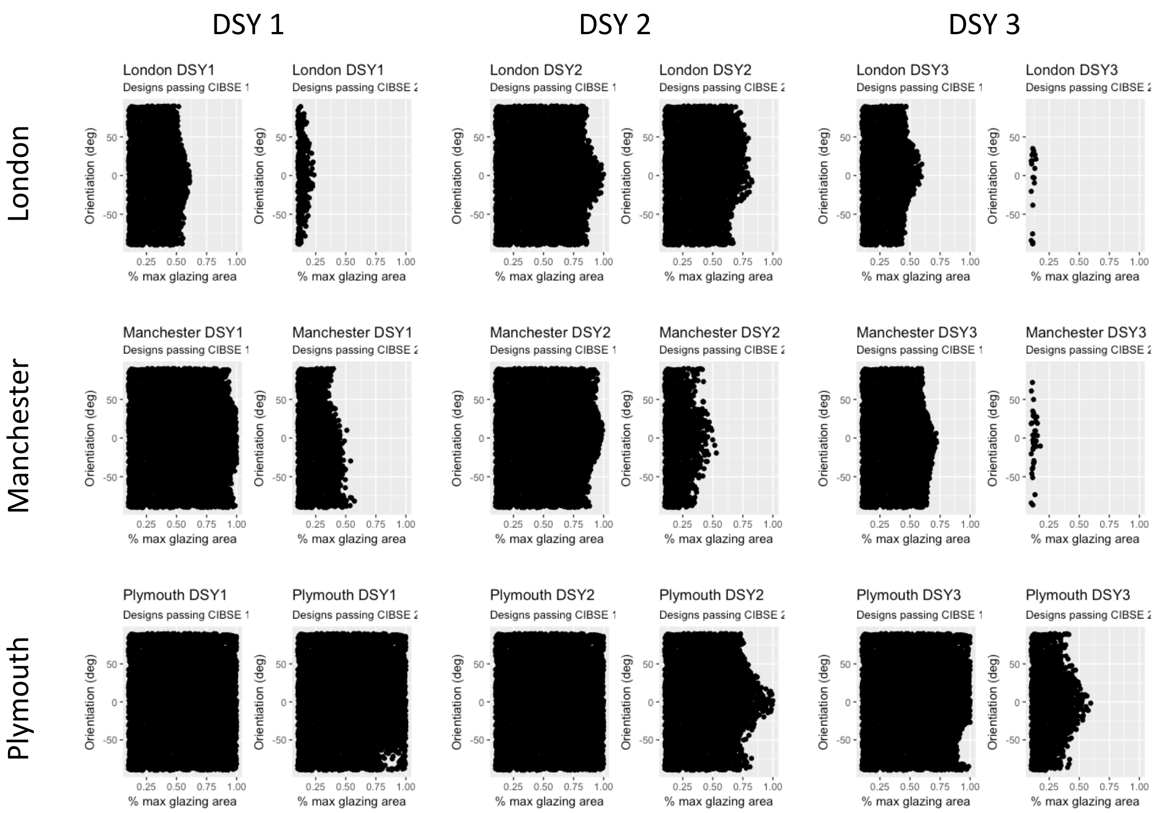


Figure 5: Plot showing the designs that pass the CIBSE 1 and CIBSE 2 criteria for each weather file

Discussion

The results in table 3 show that the % of buildings passing criteria 2 is overall less than those passing criteria 1. It also shows that a much larger percentage of buildings pass criteria 1 than criteria 2. The later as few as 0.4% of buildings pass criterion 2 for London DSY3. The percentage of buildings passing both criteria is the same as those passing criterion 2. Further investigation has shown that all buildings that passed criterion 1 passed criterion 2.

The results of the sensitivity analysis show how the biggest factor influencing both criteria 1 and criteria 2 was the glazing area. Across all weather files, the sensitivity of both criteria to the glazing area was between 0.79 and 0.97 (criterion 1) and 0.25 and 0.94 (criterion 2). Of the remaining variables, orientation has the greater influence, but this is not significantly more than the influence of the insulation location, overhang and the total wall / roof slab insulation thickness. Interestingly the amount of thermal mass appears to have limited influence on the overheating response in all cases (at least compared to the other variables).

Knowing that the orientation and the glazing were the biggest influencers of both overheating criteria, we plotted the buildings that pass each of these criteria in Figure 5.

The results of this analysis show a wide range of compliant designs. Not surprisingly, the buildings with the lowest glazing consistently pass both criteria in all cases. The exception is for London DSY3 and Manchester DSY3, where only a handful of buildings pass the criterion 2. The orientation also influences the overheating. In Figure 4, we can see a pattern where the number of compliant buildings increases for both criteria (though particularly criterion 2) where the lounge side of the building is facing due south (i.e. *orientation = 0 degrees*). This can best be seen for Plymouth DSY3 (criterion 2) and London DSY 3 (criterion 3).

It is well understood that solar radiation plays an important part in overheating. However, our results show that even with the same building designs, the pattern observed is different. For example, comparing the results of criterion 2 for Manchester DSY1 and DSY2 we see different patterns. Both have around the same number of compliant designs, but the *pattern* of where those designs lie is different (see Figure 4).

We expect the number of buildings passing DSY2 would be less, which is true (27.2% *vs.* 35.7%), but the pattern of building designs in DSY1 is more skewed to an orientation of -90 degrees, whereas the DSY2 has more high glazing options at orientations around 0 degrees.

Given that criterion 2 is based on a single day's-worth of overheating, there are several possible explanations for this pattern. One explanation is that cloud cover may play a major role. Since the hottest day will trigger criterion 2, then on this day, it may be that there is more cloud cover in the weather file during different periods of the day. There needs further investigation, but if cloud cover can influence the design in this way, then this has important implications for weather file design.

Conclusion

We have demonstrated the results for a *PassivHaus*-style building design. The results show that the glazing and orientation are the biggest determinants over the overheating risk. Further work is required to investigate these same relationships for other passive and low energy design methodologies. Also, these findings may also only be relevant to the CIBSE overheating criteria. Further work may also consider looking at other overheating criteria.

However, it is clear from the results that it is very likely that the relative glazing area is the biggest design parameter affecting the amount of overheating in passive-style buildings.

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Passive Design Strategies for Energy Efficient Housing in Nigeria

Maryam Abbakyari[1] and Ahmad Taki[1]

[1] Leicester School of Architecture, De Montfort University Leicester, LE1 9BH UK

Abstract: The varying manifestations of climate change are greatly impacting our lives and livelihoods principally due to the activities of industries that pollute the atmosphere and use up non-renewable resources to fuel our growth and development. It is estimated that approximately one third of the worlds energy is consumed within buildings of which approximately 60% is through air conditioning systems. The aim of this research is to investigate various passive design strategies to improve the energy efficiency of a typical mass housing type in Nigeria. A case study of mass housing was carried out to select a sample that was used to conduct a thermal analysis using EnergyPlus tool. The first stage was optimising the building fabric which involved proposing a sustainable alternative to the conventional masonry material. Next was the application of passive strategies aimed at achieving lower energy load for cooling. The building simulation showed a significant 30% reduction in cooling. This is significant particularly because of the inadequate and unreliable electricity supply in Nigeria which leads to reliance on fuel based backup power generation systems.

Keywords: climate change, air conditioning systems, passive design, energy efficiency

Introduction

Climate change is having a tremendous effect on our fragile ecosystem where the acceleration of its effects is believed to have occurred as a result of human activities that release greenhouse gases (GHG) into the atmosphere (Golubchikov and Badyina, 2012). It is estimated that the building sector accounts for 40% of the world's energy consumption and related one-third of global GHG emissions where approximately 80% of the energy is through air conditioning systems and artificial lighting (UNEP-SCBI; Rupp et al, 2015). In the 4th Assessment Report of Intergovernmental Panel on Climate Change (IPCC AR-4) it is estimated that GHG emissions from building related activities could nearly double by 2030. However, the report concluded that the building sector has the largest potential for reducing GHG emissions. Studies have shown that the most effective and least expensive way of reducing the effects of climate change is by using less energy (Lechner, 2014).

The power sector in Nigeria is faced with a crisis of persistent epileptic supply of electricity due to vandalism of pipelines and shortage of gas to the power plants. The amount currently generated is far below the expected supply load of 12,800MW for the current infrastructure (Sambo et al, 2012). This short fall has left at least 50% of Nigerians without access to electricity which consequently led to reliance on back-up generators by household and businesses. The power produced by these petrol or diesel generators is estimated to represent about 80% of installed capacity of the national grid (Oyewunmi and Iwayemi, 2016). Carbon emissions from domestic generation in Nigeria are greater than those from workplaces, buses and trucks, and pose potentially risky challenges to people's health and the environment due to long-time exposure (Oseni, 2016). Hence, there is urgent need for the implementation of energy efficiency in domestic building design and construction in Nigeria.

Literature Review

Energy efficient buildings

The Chartered Institute of Building Service Engineers (CIBSE, 2012) describes an energy efficient building as one that provides the required internal environment and services with minimum energy use in a cost effective and environmentally sensitive manner. Research has established that by making relatively simple alterations to the building at the concept design stage can have a significant effect on the potential energy performance. Some of the environmental and economic benefits in delivering energy efficient buildings are reduced running costs, reduced environmental impacts, improved ambient condition and increased equipment life (Abimaje and Akingbohungbe, 2013).

Strategies for Energy Efficiency in Buildings

Strategies for Energy efficiency in buildings as described in CIBSE Guide (2012) are approaches through which the energy consumption of a building can be reduced while maintaining or improving the level of comfort in the building. Reducing demand is the most important principle of energy efficiency strategy because it gives designers the opportunities to design buildings in a way that tends to reduce their energy demands in the early stages (CIBSE, 2012).

Lechner (2014) illustrates the energy efficient strategies in form of "A Solar Fruit Tree" stating that efficiency is the low-hanging fruit as seen in Figure 1. The "Solar Fruit Tree" shows not only all the major solar strategies, but places them at various heights in relationship to the order in which they should be picked. "Some low-hanging-fruit strategies are free or can even save money by reducing the initial cost of a building" (Lechner,2014).

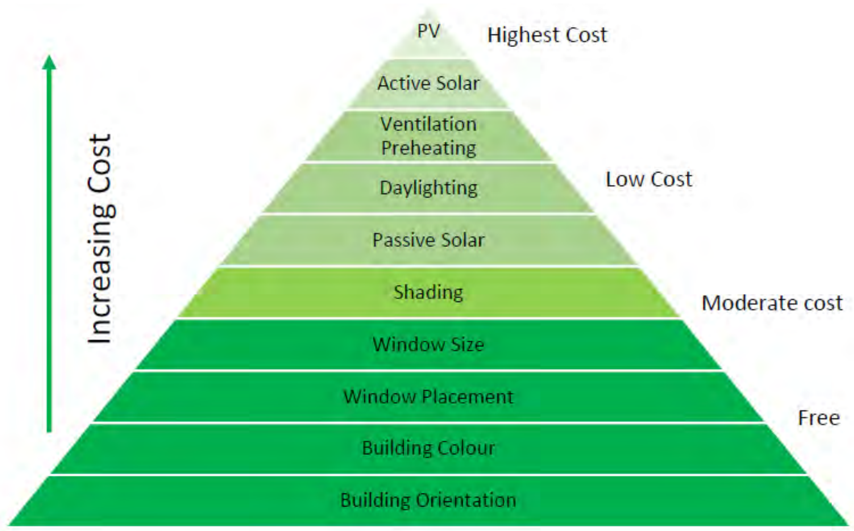

Figure 1. The solar fruit tree chart showing the free and costly strategies
Adapted from: Lechner (2014)

Passive design approach

Passive design is design that works with the environment to exclude unwanted heat or cold and take advantage of sun and breezes (Cairns Regional Council, 2011). One of the main passive design principles for buildings in tropical climates is avoiding heat gain through proper orientation, shading of walls and windows, insulation, use of thermal mass, use of heat and light reflective surfaces. To achieve the aim of this study, the solar fruit tree approach would be applied in selecting the free to low cost strategies. The elements to be investigated starting from the lowest hanging fruit are orientation, colour and window to wall ratio, and shading. Shading, although is not free would be included due to its high benefits in heat avoidance. These benefits could potentially be offset by the energy that would be saved.

Orientation

Orientation refers to the way a building is placed on site to take advantage of climatic features such as sun and cooling breezes (McGee,2013). East and west facing walls receive the highest amounts of radiation, especially during hot periods. Therefore, the best orientation in the tropics is rectangular with long axis running east-west in order to minimise solar heat gain through the long façade (Abimaje and Akingbohungbe 2013; Gut,1993).

Colour

Use of light colours on the exterior surfaces of the building fabric helps to lower heat build-up (Cairns Regional Council, 2014). Studies have shown that the total air-conditioning in many buildings can be reduced by 20% just by increasing the solar reflectivity of the roof and walls from a typical medium-dark value of 30% to a light-coloured value of 90%. Solar reflectivity, which is also known by the term “albedo”, is a number that indicates how much of the solar radiation is reflected from a surface. An albedo of 0 indicates that no sunlight is reflected while an albedo of 1 indicates that all sunlight is reflected. The colour white has the highest solar reflectivity with an albedo of about 0.9 (90% is reflected) if it is fresh, clean, and glossy (Lechner, 2014).

Window size and location

Glazed windows and doors have very important functions in letting in natural light and fresh air. However, in the tropics, they are the main sources of undesirable heat gain reaching up to 87% (McGee,2013). The ideal design would have only south and north windows and no east or west windows. When that is not possible, the number of east and west windows should be minimized and the number of north and south windows maximized. Making windows on the east and west facades smaller than those on the north and south facades is another free strategy to save energy for cooling (Lechner, 2014).

Shading

Shading is one of the most important strategies especially in the tropics where the solar angle is overhead throughout the year. (Stouter,2008). Shading buildings and outdoor spaces helps to moderate temperatures, improves comfort conditions and saves energy. External shading devices are the most effective barrier against the sun by preventing up to 90% of heat gain (Lechner, 2014; McGee,2013). Most shading devices consist of either vertical fins, horizontal overhangs or both combined. The overhangs have many variations and are the best choice to use for the south façade particularly in the tropics where solar heat gain is not desired. The eaves should be at least 800mm wide and located far above windows to ensure they adequately shade windows and walls from direct solar radiation (Cairns Regional Council, 2014).

Methodology

Sample location

The sample selected for the investigation is in Abuja which is Federal Capital Territory of Nigeria. Abuja is located within Latitude 9° 03' N and Longitude 7°29' E with altitude highs of

476m above sea level. It is surrounded by highlands, hills, savannah grassland and covers a land area of about 8000km^2. Abuja under Koppen climate classification features a tropical wet and dry climate. March is the hottest month and August the coldest with average temperatures of 30°C and 25°C respectively. Average humidity range in Abuja falls between 60-70% (Abdulkareem and Al-Maiyah et al. 2015).

Research Strategy

The methods applied for the research are analytical where a review of mass housing was carried out and experimental research which involves the computer based simulation to quantify the energy consumption of the sample as well as the manipulation of the variables to evaluate the potential impact on the energy load for cooling. This method was selected as appropriate due to its characteristics of being a standard tool for conducting experiment which also reveals objective results.

Sample description

The sample selected for study is a three -bedroom bungalow which is a typical mass housing type for the average family in Nigeria. The wall construction method consists of the conventional sandcrete blocks with plaster on both sides while the roof is a pitch roof with long-span aluminium roofing sheet covering. Refer to Figures 2 and 3 for the floor plan and cross-section of the building.

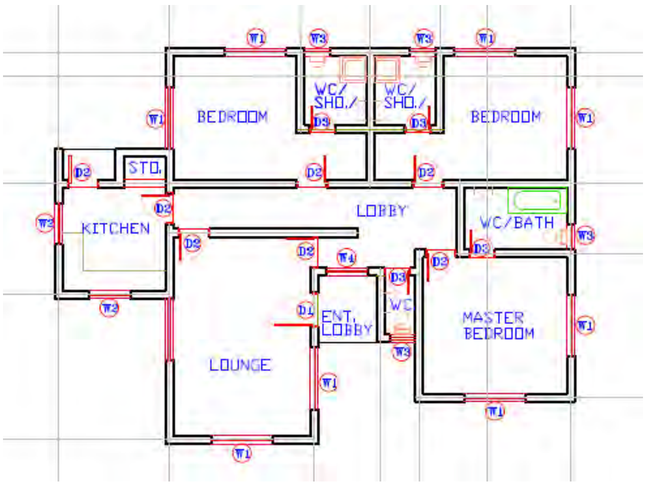

Figure 2. Floor plan- not to scale

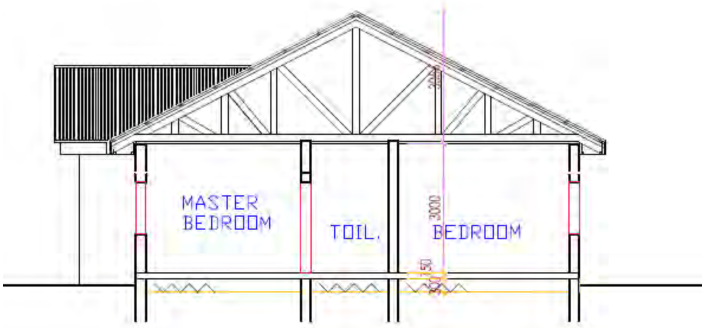

Figure 3. Cross section- not to scale

Building Simulation

EnergyPlus tool was used to construct a base-case model for assessing the thermal performance of the building for a range of dynamic thermal simulations. The constant variables throughout the simulation were building activity template, occupied floor area, occupancy, airtightness and lighting (LED-3.3W/m^2).

Energy Simulation of Base-Case Model

The base-case model was simulated to determine the annual energy consumption for cooling the building. The result shows the cooling load of **11245kWh**. This value would be used as the base for comparison after applying the passive design measures to improve the energy efficiency of the building.

Thermal Analysis Using Passive Design Strategies

The strategies for heat avoidance were used with the aim of investigating the effect of employing free to low cost strategies on the energy consumption for cooling the building. The elements were selected based on passive design strategies suitable for the tropical climate of Abuja. Before applying these strategies, the walls were replaced with a sustainable alternative. Compressed Earth Bricks was proposed to be used in place of the sandcrete blocks due to its cost effectiveness and better thermal properties. A reduction in cooling load of 8% was achieved.

Orientation

The model was analysed with the façade facing different orientations in where the North facing gave the least amount of cooling load. This gave a cumulative reduction of 12%.

Colour

The review of literature reveals that by simply changing the roof colour from red to reduces heat gain into the building. The simulation results gave a lower roof temperature by approximately 3^{o}C. A further cumulative reduction in cooling load of 16% was achieved.

Window to Wall Ratio(WWR)

To reduce the effect of direct solar radiation, the east and west facing windows were reduced while increasing the size of the north facing windows to let in cool air. These changes resulted in overall lower window to wall ratio from 24.8% to 21.4%. A cumulative reduction in cooling load of 19% was achieved.

Shading

Shading is not free but cost effective due to the amount of reduction in cooling load achieved. An extension of roof overhang was proposed as the most suitable low cost strategy for shading the windows in this analysis. A depth of 1070mm was calculated to shade the whole window but a depth of 1100mm was used to further shade part of the walls below the window sill. In addition, venetian blind was added to the outside of the east and west facing windows. This resulted in a cumulative reduction in cooling load of 30%.

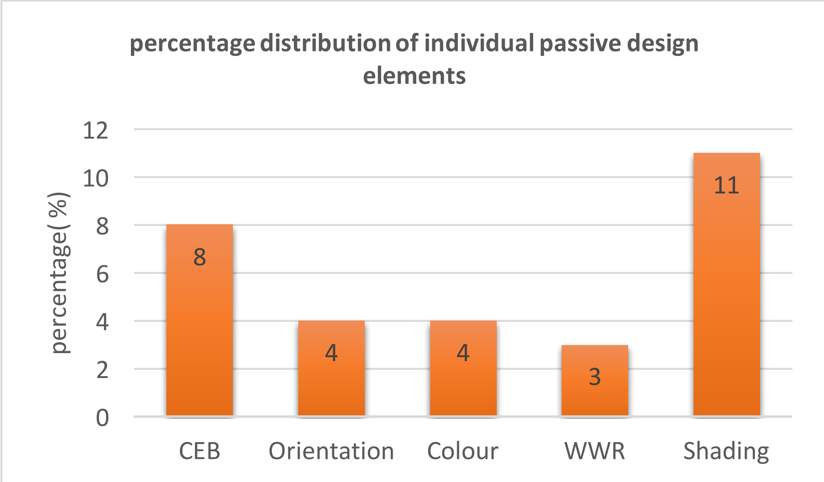

Figure 4. Percentage distribution of passive design elements

Energy Simulation of Improved Model

The energy simulation of the improved model resulted in a lower annual cooling load of **7928kWh.** This gives a difference of **3317kWh** between the base-case model and the improved model which is a **30%** reduction in cooling load as shown in Figure 5.

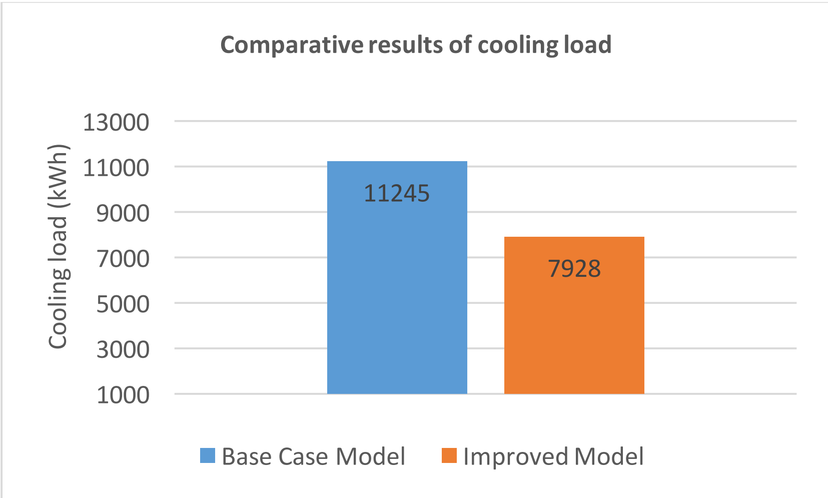

Figure 5. Comparison of cooling load between base case model and improved model

Conclusion

In recognition of the impact of climate change on the environment, this study investigated the effect of free to low cost passive design strategies on the energy efficiency of mass housing in Abuja. Abuja being the capital city of Nigeria is a focus of economic activities that has led to an influx of people contributing to a rise in housing demand in the city. In view of this, the implementation of passive design strategies is a simple and cost effective means of providing energy efficient housing.

This research reveals that heat avoidance is the first and most important passive strategy for energy efficient buildings. These were best achieved by picking the 'lowest hanging fruit' i.e. beginning with the simple and free strategies before reaching the costly ones. The masonry material was first replaced with Compressed Earth Brick (CEB) as a sustainable alternative to the conventional sandcrete blocks before applying the passive design strategies. The overall performance of the building gave a result of 30% reduction in cooling load. Overall this research has proven that energy efficiency can be achieved at low cost. The outcome concurs with IPCC AR-4 report where it states “the energy consumption in buildings can be cut by an estimated 30-50% without significantly increasing investment costs”.

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Passive cooling consideration in the effective planning and design of public buildings in Nigeria

Solomon Adewumi[1], Joseph Fadamiro[2], Vincent Onyango[1], Dumiso Moyo[1] and Husam Alwaer[1]

[1] Architecture and Urban Planning, University of Dundee
[2] Federal University of Technology Akure, Nigeria

Abstract: The rapid increase in the growth of Nigerian cities as a result of mass rural-urban migration has led to a demand for more public buildings. The ongoing campaign on sustainability backed up with the statistics that confronts us daily have necessitated the need to deliver more environment-friendly public buildings. This study is aimed at enhancing sustainable utilization of energy through passive cooling in the planning and delivery of public buildings with optimum design condition for users' comfort in Nigeria. The objectives are: (i) to identify the factors that enhances the passive performance of a building (ii) to measure these factors through case study survey and post occupancy evaluation of three existing public buildings (iii) to arrive at optimum design conditions using passive cooling in public buildings. Findings showed inadequate consideration of the design strategies that enhance the passive performance of a building due to dependence on the active cooling means in public buildings visited. The paper recommended a policy framework for the planning of public buildings and canvassed the need for professionals in the built industry to consider how key design strategies can be considered in the early stage of their design decisions that will lead to sustainable public buildings.

Keywords: Energy, passive cooling, policy, public buildings, thermal comfort

Introduction

According to recent statistics, the building industry accounts for more than 40% of the total energy consumption (Edward, 2012; Santamouris, 2005). While the awareness on climate change continues to intensify, it is needful to cut energy consumption to a reasonable amount because the quality of urban life and the global environmental quality of cities is dependent on net energy consumption (Santamouris, 2005). Consequently, energy efficiency is now a basic requirement for the designing professions (Roaf and Hancock, 1992). Going forward, active cooling which involves the use of air conditioners to maintain thermal comfort in a building needs to be critically reconsider for a passive approach for an effective planning and delivery of building projects (Ghiaus and Roulet, 2005).Passive cooling strategy employs a non-mechanical means to achieve a comfortable indoor temperature (Kamal, 2012; Larsen, 1998). Passive cooling helps to reduce the temperature of buildings without need for energy or power consumption (Taleb, 2014). Some of the passive cooling strategies include: solar shading; insulation; induced ventilation techniques (such as solar chimney, air vents, and wind tower); relative cooling; evaporative cooling; and earth coupling among others (Adewumi, 2012; Santamouris and Asimakopolous, 1996). However, due to the differences in climate and technological know-how, the passive cooling strategy adopted for use in a particular region may not be applicable for use in another context (Taleb, 2014). For example, design solutions employed in the tropics is likely to be a misfit in a temperate region.

This paper attempts to investigate how passive cooling consideration can enhance effective planning and design of public buildings with optimum design condition for users in Nigeria. This is with the rationale that building occupants are not passive in relation to their thermal environment as they tend to seek comfortable environments (Humphreys, 1992; Lush, 1992). The choice of public buildings is justified on the basis its energy demand is higher compared to residential buildings (Liu et al, 2012). Other sections of the paper include: section 2 which is a critical review on passive cooling identifying the factors that enhances the passive performance of buildings; section 3 explains the methodology of the study while section 4 highlights the results and discussion of findings; and section 5 gives the conclusion and recommendations.

Theoretical concepts of passive cooling

Passive cooling operates with the principle of preventing heat from entering into the building or removes it once it has entered into the building (Kamal, 2012). This principle helps to reduce energy consumption from peak cooling load. Ability to maintain a cool environment during warm periods is crucial for optimum utilization of human resources and productivity (Santamouris and Asimakopolous, 1996). With its environmental, indoor air quality, and economic benefits, the passive cooling of a building can be enhanced by its passive performance which is a function of its:

(i) Planning and design and;
(ii) Passive cooling strategy.

Planning and design

Jackson and Jackson (1997) suggested the following design attributes which define the passive performance of a building as explained:

Building Orientation
A building's orientation is its position with respect to the geographical coordinates. Proper building orientation increases the energy efficiency of a building which makes the building cheaper to maintain as it reduces the chances for the need for heating and cooling systems. Givoni (1994) asserts that the main consideration in building orientation is the positioning of its windows. High penetration of solar energy through large openings in a hot weather can increase the indoor temperature causing thermal discomfort and increasing the building's cooling load. A south-facing window will most times receive most sunlight while a north-facing window will only have it on few occasions in the early morning and late evening (Littlefair et al, 2000). A detailed site analysis is therefore essential early at the planning phase which will provide adequate information on temperature, wind, humidity, rainfall, and solar radiation among others.

Building shape
The geometry of a building in terms of its width, depth, and height determines its passive performance. To enhance passive cooling, buildings should be compact with surface area of its external envelope been kept as small as possible so as to reduce the heat flow into the building.

Windows and opening sizes
Size of windows needs to be considered to optimise passive cooling in a building. Large openings tend to admit more solar radiation than smaller ones. Givoni (1994) posited that heat gain through windows per unit area is much higher than through walls or roof especially in the absence of sun shading devices. Building design in a tropical area should aim at minimizing heat gain indoors and maximizing evaporative cooling (Lawal et al, 2012). Ventilation rate should be kept to the minimum required for health to reduce the heating of the interior by the outdoor air. Proper ventilation can improve thermal condition in indoor spaces and decrease energy consumption of air conditioned buildings (Santamouris, 2005; Routlet, 2005; Roaf et al, 2007)

Shading characteristics of building
Shading devices are essential for reducing the heat (solar radiation) entering buildings which helps to improve thermal comfort and reduce cooling loads (Littlefair et al, 2000) by blocking 90% of solar radiation. Shading devices can either be adjustable or fixed. The latter which are architectural elements provide means to articulate building facades while the fixed which can either be external or internal are operable. Examples of shading devices include overhangs, colonnades, movable screen and shutters.

Passive cooling techniques

In hot climates characterized with high solar radiation all through the year, passive cooling is one of the most difficult problems to solve. The simplest and the most effective solution for active cooling is to introduce air conditioning. However, as these systems do incur high initial cost with huge operational cost for installation, energy and maintenance, a passive cooling system is more desirable. Givoni (1994) identified the following seven passive cooling strategies: (i) comfort ventilation; (ii) nocturnal ventilation cooling; (iii) radiant cooling; (iv) direct evaporative cooling; (v) indirect evaporative cooling; (v) soil cooling; (vi) cooling of outdoor spaces.

Methodology

Case study and survey research designs were adopted in order to achieve the aim of this study. The study entails site visit to selected public buildings using events hall as a representative sample. This is justified on the basis of its high cooling load demand compared to other public buildings in Nigeria. Emphasis in the course of the case study was on:

(i) The passive performance of the building in terms of its building orientation; shape; windows and openings sizes; and shading characteristics of building;
(ii) The passive cooling techniques of the building

Sequel to the case study, a Post Occupancy Evaluation was conducted in a survey where self-completed questionnaires were administered to investigate the level of thermal comfort achieved by building users. This was conducted in the rainy season (April-October); harmattan (December- January); and the dry season (November to March). Since Nigeria falls within the tropics where the climate is seasonally damp and very humid, the atmospheric weather condition of the study location ranges between 28^{0}C to 32^{0}C. The thermal comfort was measured in qualitative terms based on the perception of each of the respondents which were randomly selected. The public buildings are:

(i) Mapo city hall Ibadan
(ii) Archbishop Abiodun Adetiloye Hall, Ado-Ekiti, Nigeria
(iii) Lagos city hall, Lagos Nigeria

Results

Mapo city hall, Ibadan Nigeria

This section of the paper presents the result from both the case study conducted and the post occupancy evaluation (POE) which investigated respondents' perception of thermal comfort.

Building orientation and shape
The hall covers an approximately 3810.24 square meters on the site. The main building mass is oriented in the east west direction allowing maximum solar radiation.

Window size and openings
The use of large openings in place of windows at the ground floor enhances more ventilation as it aids air flow. According to the design of the building, the north and south elevation on the ground floor level has no windows except these openings. Windows are only placed at the gallery floor level (see figure 1).

Shading characteristics of building
The deep verandah and balcony at the ground floor and upper floor serves as a shading device. Tropical climate requires consideration for effective shading device for building elevations and passive cooling for users comfort. The hall employed basically for its elevations, horizontal shading device with the use of long and deep verandahs supported with columns (see figure 2). There are no window hoods in any of the elevations.

Figure 1: The interior view of the hall
Source: Researcher's field survey, 2012

Figure 2: Long and deep verandahs as a shading device

Passive cooling strategy
The hall employed both active and passive cooling techniques in achieving thermal comfort for the occupants. However despite the building's design which encourages passive cooling, the hall makes use majorly the active means of cooling with the aid of standing fans and the split unit air conditioning system. There are 22 number split unit air conditioning systems equally placed on both sides of the building interior.

Post occupancy evaluation
A total number of 120 post occupancy evaluation questionnaires were administered, 115 questionnaires were retrieved out of which only 80 are regular users of the hall whose responses will be used for the post occupancy evaluation of the building. During the rainy season, 57 respondents (71.3%) achieved thermal comfort by passive cooling, 46 (16.3%) did not and 10 (12.4%) were unconcerned. In the harmattan season, 46 (57.5%) achieved thermal comfort, 25 (31.3%) did not and 9 (11.2%) were unconcerned. However for the dry season of the year, 39 (48.8%) achieved thermal comfort, 34 (42.5%) did not, while 7 (8.75%) were unconcerned.

Archbishop Abiodun Adetiloye hall, Ado Ekiti Nigeria

Building orientation and shape
The main building mass is oriented in the N-S direction presenting minimal solar radiation on the building façade

Window size and openings
Some windows especially at the gallery level have hoods of little thickness which to some extent block solar radiation from entering the building interior.

Shading characteristics of building
Cross ventilation was adopted to enhance air flow within the building interior. This was also aided with the use of high level window in a process known stack effect. To shade incoming solar radiation, the building employed for most of its elevations deep verandah of about 2.4metres supported with columns (see figures 3 and 4).

Figure 3: The air-conditioning unit of the hall
Source: Researcher's field survey, 2012

Figure 4: The deep veranda of the hall
Source: Researcher's field survey, 2012

Passive cooling strategy
Despite the building design, it still relies on both the active and the passive cooling techniques to enhance thermal comfort for its occupants. The active cooling systems are the split type air conditioning unit and hanged mechanical fans. Although the building is cross ventilated, the active cooling system is used most of the time for comfort.

Post occupancy evaluation
A total number of 100 post occupancy evaluation questionnaires were administered, 90 questionnaires were retrieved out of which only 60 are regular users of the building whose

responses will be used for the post occupancy evaluation of the building. During the rainy season, 45 respondents (75%) achieved thermal comfort by passive cooling, 9 (15%) did not and 6 (10%) were unconcerned. During the harmattan season, 39 respondents (65%) achieved thermal comfort, 13(21.7%) did not and 8 (13.3%) were unconcerned. 38 (63.3%) achieved thermal comfort, 17 (28.4%) did not while 5 (8.3%) were unconcerned during the dry season.

Lagos City Hall, Lagos Nigeria

Building orientation and shape
The building approximately occupies about 9214 square meters on site.

Shading characteristics of building
The only noticeable shading device noticed are the deep roof overhang and the columns supporting the roof deck (see figure 5). Also at the approach view on the first floor is a deep rectangular canopy which shades the lobby leading to the banquet hall.

Figure 5: The deep roof overhang of the hall
Source: Researcher's field survey, 2012

Figure 6: Use of courtyard in the hall
Source: Researcher's field survey, 2012

Passive cooling strategy
The design of the building is such that passive cooling should be adequate with the incorporation of two courtyards of about 420 square meters each (see figure 6). However, the building operates entirely with active cooling. In fact there is a chiller pump room which supplies all the floors in the building the required fresh air through a central control unit. At times, the two courtyards are used to achieve thermal comfort of occupants

Post occupancy evaluation
A total number of 180 post occupancy evaluation questionnaires were administered, 170 questionnaires were retrieved out of which only 145 are regular users of the building whose responses will be used for the evaluation of the building. During the rainy season, 96 respondents (66.2%) achieved thermal comfort by passive cooling, 37 (25.5%) did not and 12 (8.3%) were unconcerned. During the harmattan season, 91 respondents (62.8%) achieved thermal comfort, 40 (27.6%) did not and 14 (9.6%) were unconcerned. However for the dry season of the year, 80 respondents (55.2%) achieved thermal comfort, 47 (32.4%) did not while 18 (12.4%) were unconcerned.

Discussion

The average thermal comfort of respondents varies with the three seasons of the year. Except for the Mapo city hall, the post occupancy evaluation indicates that respondents attained thermal comfort more in the rainy season. Findings showed that building design is a crucial factor that enhances the thermal comfort level of building occupants. The Adetiloye hall recorded the highest percentage of respondents that achieved thermal comfort with an average of 68% of respondents all year round. Lagos city hall had 61% of respondents while Mapo city hall had 52%. The minimal solar radiation experienced by the Adetiloye hall due to the building's orientation helps to reduce the cooling load. The hall also adopted the stack effect which enhanced adequate air flow in and out of the building. The two courtyards enhances air flow in and outside the Lagos city hall which helps to maintain a good air flow. The Mapo city hall recorded lesser percentage due to the building design and orientation which allows high solar penetration into the building interior.

Aside from the building design, the use of natural landscape elements was also observed to contribute to good microclimate of the events hall visited. This also aids the thermal comfort of building users. At the Mapo city hall, non-usage of landscape elements especially plants and shrubs resulted to the low microclimate condition of the site (see figure 2). This is not ideal as landscape elements are vital in maintaining a good microclimate. The conscious landscaping of the Archbishop Abiodun Adetiloye and the Lagos city Halls is commendable with diverse plant types, shrubs which contributed immensely to the good microclimate of the site (see figures 7 and 8).

Figure 7: The Archbishop Abiodun Adetiloye hall
Source: Researcher's field survey, 2012

Figure 8: The landscape design of the Lagos city hall

Passive cooling needs to be well thought of at the early stage of the design process. This undoubtedly should continue at the design phase till the completion of the entire building project. Passive cooling if well-conceived and thought of can help to realise the cooling load thereby enhancing the utilisation of energy and most importantly the thermal comfort of building occupants at certain seasons of the year without the use of active or mechanical cooling means. What is needed to enhance passive cooling in Nigeria is a policy framework which advocates for assessing the 'passive cooling passport' of a building especially public building prior to its approval for physical development. This will in a way undoubtedly compel professionals in the built environment to consider the following recommendations among others which will enhance passive cooling in the design of public buildings: (i) Buildings should be properly oriented so as to reduce solar heat gain in the building interior. Orientation towards wind breezes will enhance natural and cross ventilation; (ii) Glazing area and in fact glass performance should be optimum. It is advisable to use low E- glass to avoid having buildings behave like a greenhouse; (iii) Shading is expedient for solar control performance. Windows should be large enough where there is no direct solar radiation and vice versa; (iv) Landscape elements enhance passive cooling in the design of public buildings.

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Determining the courtyard thermal efficiency and its impact on urban fabric: A contextual study of Baghdad, Iraq

Omar Al-Hafith[1], Satish B K[1], Simon Bradbury[1] and Pieter de Wilde[2]

[1] Plymouth University, ADA School, Plymouth, PL4 8AA, UK, omar.al-hafith@plymouth.ac.uk

Abstract: Many researchers advocate readopting the courtyard pattern in hot climate regions for being more thermally efficient than the modern western ones, such as the detached housing. The courtyard helps through reducing heat gain and having sufficient natural ventilation to have a comfortable indoor environment. But, it is suggested that this building pattern loses its efficiency by being out of its compact urban fabric context due to having high exposure to the solar radiation. Aiming at finding a thermally efficient solution for the hot climate regions, this research investigates the thermal efficiency of courtyard pattern and examines its relevance in the present urban context. To achieve this aim, the thermal performance of a courtyard and a detached non-courtyard house was simulated. The courtyard house was tested in two locations: a traditional compact urban fabric and a modern less compact one. DesignbBuilder simulation tool was used for this purpose. The simulation results are derived from fieldwork carried out in Bagdad, where both traditional and contemporary neighbourhoods can be found. They clearly demonstrate the efficiency of courtyard pattern in the compact urban environment. These results support adopting the courtyard pattern in contemporary and future buildings, with due consideration for the urban environment.

Keywords: Baghdad, DeisgnBuilder simulation, Courtyard buildings, Thermal efficiency

Introduction

The thermal performance of buildings has been one of the main considerations in building design. It affects occupants health and productivity in addition to its impact on buildings' energy performance (Indraganti and Rao 2010). In the hot-arid climatic zone, many studies advocate re-using the traditional courtyard pattern to achieve a thermally comfortable indoor environment. Through having various experimental studies, they showed that it is more thermally efficient than the other patterns, such as the detached, semi-detached and row patterns (Ratti, Raydan et al. 2003; Manioğlu and Yılmaz 2008; Al Jawadi 2011). Its main characteristic is that it includes an open space in the building's core to which all spaces access and open to get light and ventilation. Supported by other environmental elements, such as the thermal mass, the basement and the wind-catcher (Behbood, Taleghani et al; Ali, Turki et al. 2013; Manioğlu and Yılmaz 2008), the courtyard works to regulate buildings' thermal conditions (Sthapak and Bandyopadhyay 2014; Edwards 2006). Its environmental performance depends on two environmental strategies: to protect the building for heat gain and to reduce temperature through, basically, controlling building exposure to the solar radiation and having natural ventilation (Al-Hemiddi and Megren Al-Saud 2001; Muhaisen 2006). But, it is suggested that its thermal performance is highly governed by being in a compact urban fabric (Khan and Majeed 2015; Behbood, Taleghani et al. 2010), which is significantly different from the modern less compact one (Al-Thahab, Mushatat et al. 2014).

Out of its context, its performance might reverse as courtyard buildings will get higher heat gain resulted from having a larger area exposed to the direct solar radiation and heat exchange (Gupta 1987; El-deep, El-Zafarany et al. 2012).

Aiming at determining the thermal impact of having a courtyard in buildings and the possibility of adopting the courtyard pattern in the modern less compact urban fabric, this research investigates the thermal performance of a courtyard building and a modern detached building in Baghdad, which has hot climate and both building typologies. It also tests the change in the courtyard building's thermal performance if it is moved to a context of modern less compact urban fabric.

Research aim, methodology and limitations

Within the ongoing efforts to define a thermally efficient solution for the hot climate regions, this research aims to investigate the thermal performance of the courtyard pattern. It focuses on determining the thermal impact of using the courtyard, this pattern's featured environmental element, and testing the urban fabric impact on its performance.

This study used the experimental research method to determine the relationships between buildings' thermal performance, their urban context and the existing of the courtyard. The experiment included using DesignBuilder as a simulation tool, which has been widely used to simulate buildings thermal performance with sufficient accuracy (Baharvand, Ahmad et al. 2013). Baghdad, the capital of Iraq, was selected as a case study and one of its traditional courtyard houses was used as a sample. This city has hot climate and traditional and modern housing patterns. The selected Baghdadi courtyard house was used to represent three cases. The first one involved simulating the thermal conditions of the selected courtyard house in its original conditions in a compact urban fabric (TCH). The second one is similar to the first case, but with relocating the courtyard house in a context of a modern neighbourhood as a detached house (DCH). The third case involved using the same context of the second case but with closing the courtyard and placing spaces' windows on the outside, to represent the detached modern housing pattern (DNCH). Comparing the performance of three cases indicate the courtyard pattern thermal efficiency and the impact of urban fabric pattern on courtyard buildings' thermal performance.

Analysing the three cases thermal performance

Baghdad context: climate and housing patterns

Baghdad has a long and hot summer, when the temperature might reach 51.0 C° (Iraqi Meteorological Organization, 2016), while the comfort limits have been defined to be between 18C° and 30C°(Saleem 2011). Regarding Baghdad's houses, until the middle of the last century, the courtyard pattern had been used as the housing pattern in the city. However, a number of factors including the social, cultural, and political changes, the development in the construction industry and the changing in the architectural styles have led to adopt the modern western housing patterns, including the detached houses, which do not have courtyards (Al-Thahab, Mushatat et al. 2014; Mohamad 2012). Spaces' windows have been placed on the outside. The new building patterns and the use of cars have led to a less compact urban fabric with wide streets instead of being compact with narrow organic roads (Al-Thahab, Mushatat et al. 2014; Ali 2009; Mahmood 2004).

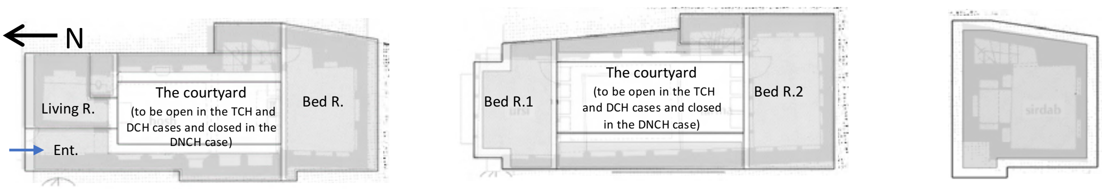
Defining the research variables

Occupants' thermal comfort has been used by studies to determine the built environment thermal performance. It is affected by a number of factors, which have been defined by researchers to include six key factors: occupants' activity level, clothing thermal resistance, air temperature, Mean Radian Temperature, air velocity and humidity (Fanger 1970; CIBSE 2016).

Building on this, occupants' thermal sensation is this research's dependent variables and the affecting factors are the independent variables. The research measures the former through considering the Operative Temperature, which is of the indices that have been developed to measure occupants' thermal sensation, but it has been defined as the most correspondent index to occupants' sensation. It combines the integrated impact of air temperature and Mean Radiant Temperature (De Dear, Brager et al. 1998; Nicol and Humphreys 2010), which are in turn affected by heat gain and natural ventilation (Doick and Hutchings 2013; Armson, Rahman et al. 2013; Atmaca, Kaynakli et al. 2007; Amos-Abanyie, Akuffo et al. 2013). Accordingly, this research's independent variables are air temperature, Mean Radiant Temperature, natural ventilation and heat gain.

Selecting and modelling the study sample

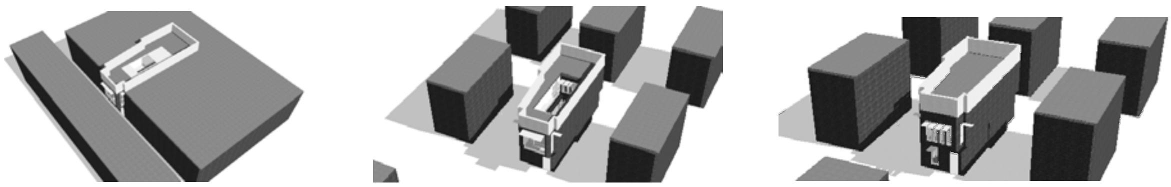
To reduce the factors that might affect the thermal performance other than the courtyard space and the urban fabric compactness, a simple courtyard house was chosen, which has the typical features of Baghdad's courtyard houses, to be used for the thermal simulation purpose. It is a two floors house with a basement and a central open courtyard (Figure 1).



Ground floor First Floor Basement

Figure 1. The selected Baghdadi courtyard house.
Floor plans were drawn in DesignBuilder depending on (Warren and Fethi 1982)

The simulation included determining the thermal conditions, the heat gain and natural ventilation of the research three cases: TCH, DCH and DNCH on the 21st of July, which is one of the hottest days in Baghdad. All of the three cases have neither mechanical ventilation nor cooling systems. They were modelled to include only natural ventilation. The research considered in modelling the three cases to make them identical in all aspects, except the considered aspects for the test (Figure 2) (Table 1) .



TCH DCH DNCH

Figure 2. The three simulated cases

Table 1. The simulated model properties

<table>
<tr><th colspan="2">The model properties</th><th>TCH</th><th>DCH</th><th>DNCH</th></tr>
<tr><td>Areas</td><td colspan="4">The house total area: 65.5 m^2 - GF. Bed R. area 17.2 m^2 - GF. Living R. area: 7.2 m^2
GF. Living R. area: 7.2 m^2 - 1st F. Bed R. 1 area: 19.2 m^2 - 1st F. Bed R. 2 area: 13.2 m^2</td></tr>
<tr><td rowspan="4">Construction</td><td>External walls</td><td rowspan="4">The option 'Bes practice, Heavy weight' used from DesignBuilder list</td><td colspan="2" rowspan="2">Super insulated block/brick wall
(This will clearly show the impact of urban fabric compactness on building's thermal conditions as it will be compared with a detached building of high insulation level)</td></tr>
<tr><td>Internal walls</td></tr>
<tr><td>Roofs</td><td colspan="2">100mm concrete slab</td></tr>
<tr><td>Floors</td><td colspan="2">Combined external floor – Heavyweight</td></tr>
<tr><td rowspan="5">Windows</td><td>GF. Bed R. windows</td><td rowspan="4">All single glassing 95% of the windows area is openable</td><td colspan="2">3 m^2</td></tr>
<tr><td>GF. Living R. windows</td><td colspan="2">1 m^2</td></tr>
<tr><td>1st F. Bed R. 1 windows</td><td>19 m^2</td><td>5 m^2 (Inevitable difference)</td></tr>
<tr><td>1st F. Bed R. 2 windows</td><td colspan="2">4 m^2</td></tr>
<tr><td>Shading devices</td><td colspan="3">Blind with high reflectivity slats (always on) and 0.5m overhang</td></tr>
<tr><td rowspan="4">Nat. Ven. settings</td><td>Windows opening schedule</td><td colspan="3">'Dwell_DomLounge_cool' (selected from the DesignBuilder's schedules list).
Windows are open during the nights and early mornings</td></tr>
<tr><td>Nat. Vent. condition 1</td><td colspan="2">Outside Min. tem. is 15C° and Max. tem. is 30C°</td><td rowspan="3">according to the thermal comfort limits</td></tr>
<tr><td>Nat. Vent. condition 2</td><td colspan="2">Min. difference between inside and outside tem. is 2C°</td></tr>
<tr><td>Nat. Vent. condition 3</td><td colspan="2">Max. inside tem. is 30 C°</td></tr>
</table>

The results: Analysis and Discussion

The results show that there are significant differences between the thermal conditions of the three tested cases (Figure 3), (Figure 4). Regarding the heat gain, the results demonstrate that heat gain happens during the night through the three mechanisms of heat transfer in buildings: convection, conduction and heat radiation (Stein 1997). From 18:00 o'clock until 00:00 o'clock, heat gain is higher in DNCH and DCH than TCH. This can be attributed to the time lag in heat radiation from the construction materials in DNCH and DCH typologies. At this time, Walls are protected in the TCH typology; they do not get direct solar radiation and, as a result, do not have stored heat radiation. On the other hand, from 00:00 o'clock until 8:00 o'clock, TCH and DCH have heat gain, which happens at the same time as occupants operate windows to get natural ventilation. This heat gain can be traced back to impact of opening the windows to the courtyard where the air temperature is higher than the outside temperature, but still have cooling impact as its temperature is less than the spaces' temperature (Figure.4- A,D,E), (Figure.5- A,D,E). The maximum measured heat gain is 0.35kW in (Bed R. 1) on the first floor of the DCH typology due to having the highest exposure to the solar radiation. As a consequence, It has the highest air temperature, the highest Mean Radiant Temperature, and the highest operative temperature, which is around 33C° (Figure 4 –A,D). The low heat gain in the first evening hours in the TCH case can be traced back to the use of the courtyard, which enables to have buildings attached to each other, which protects the outer walls from the solar radiation.

Natural ventilation works during the night time to reduce the temperature by replacing the hot air with cold one. It is more active in TCH and DCH than the DNCH (Figure. 4-E,F), (Figure.5-E,F). The courtyard stimulates air movement through having the heated air by the walls heat radiation going up to be replaced by cold air (Mohammad 2010)

As a result of heat gain and natural ventilation, spaces' air temperature and Mean Radiant Temperature change and affect the operative temperature (Figure.4-A, B, C), (Figure.5-A, B, C). The lowest measured Operative Temperature is around 21 C°, which is in the TCH'S ground floor bedroom. This space has the least exposure to the solar radiation and one of the highest heats loose through natural ventilation. In total, DNCH has the highest operative temperature. This result might be different if the tested houses are of low thermal insulation, as, in this simulation, the DCH higher exposure to the solar radiation might be overcome by the natural ventilation cooling impact and the high insulation level. On the other hand, the TCH has the lowest operative temperature. It is around 7 C˚ less than the outside temperature in the ground floor and 2 C˚ in the first floor. The open courtyard space itself provides a stable air temperature during the whole day which is up to 7.5 C˚ less that the outside temperature in the midday.

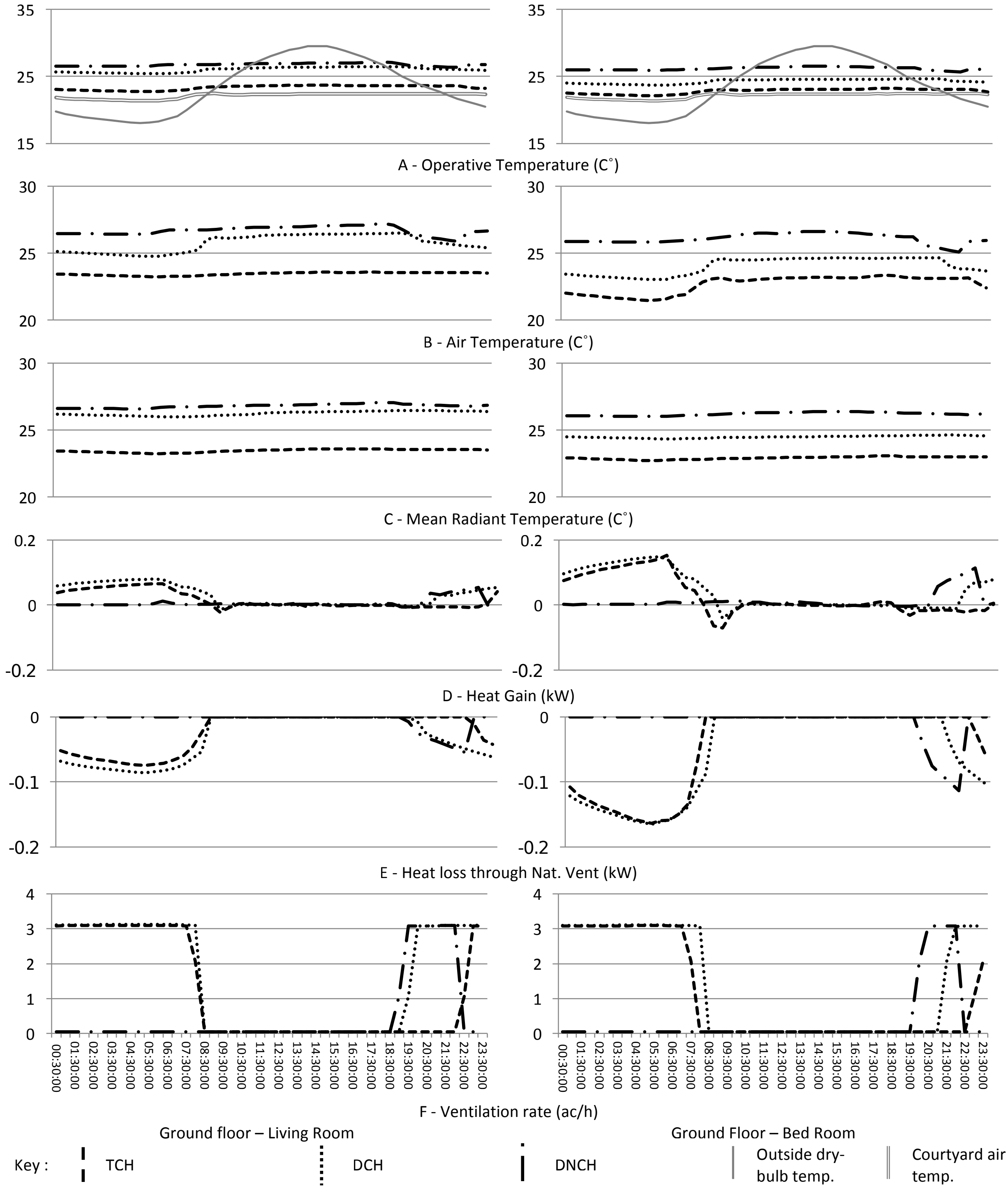


Figure 3. The ground floor two residential spaces thermal conditions.

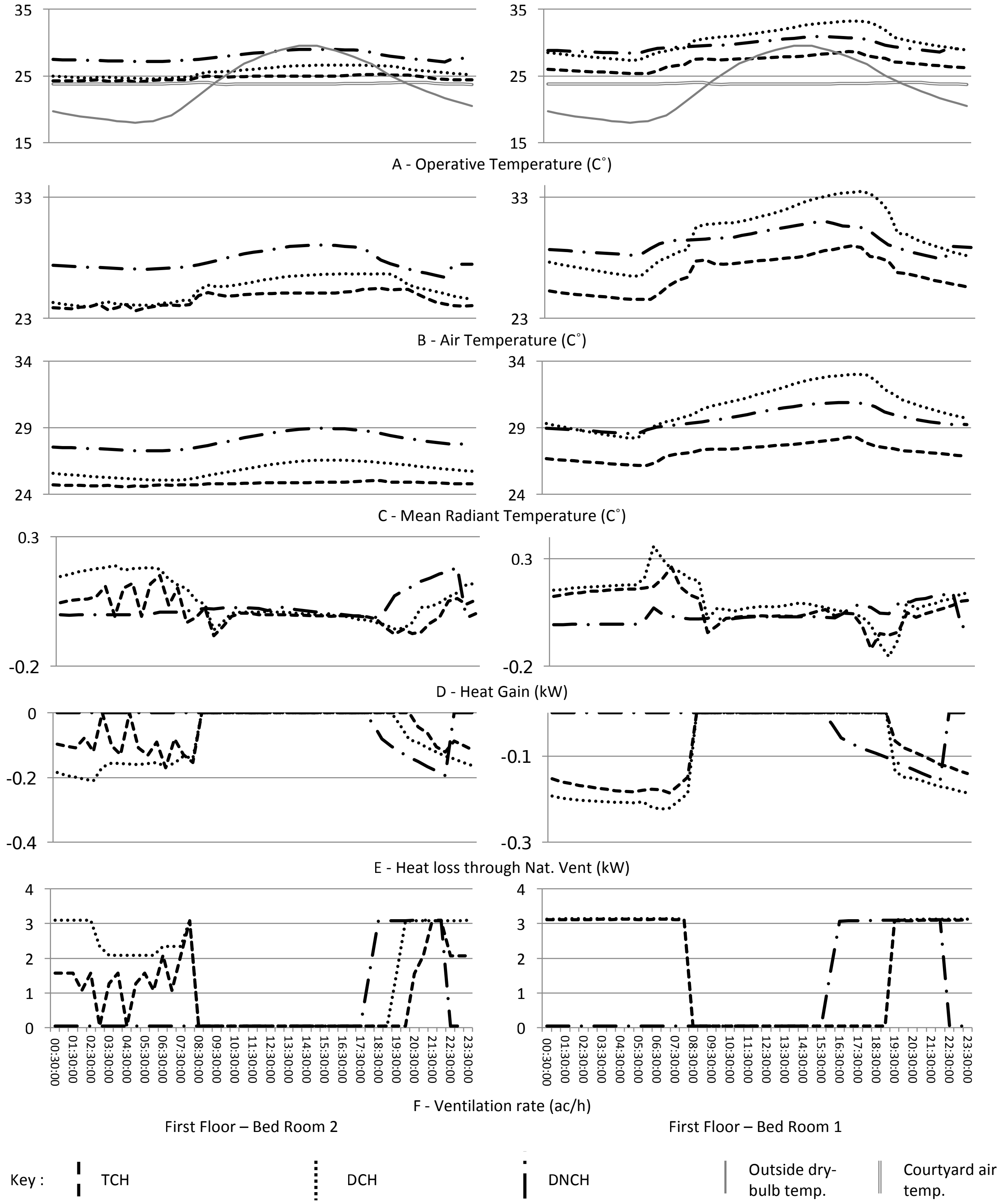


Figure 4. The first floor two residential spaces thermal conditions.

Conclusions and Recommendations

The courtyard pattern might offer an opportunity to have thermally comfortable indoor environments. Comparing the thermal performance of the TCH and the DNCH cases indicate the courtyard pattern efficiency, which can be traced back to the use of the courtyard element inside buildings. It enables to have buildings attached to each other as spaces have their openings to the inner courtyard. On the first hand, this protects external walls from the direct solar radiation and the resulted heat gain. On the other hand, it offers air with lower temperature to be used to have sufficient natural ventilation.

This research demonstrates that the courtyard house offers its maximum thermal efficiency by being in a compact urban fabric. This efficiency decreases by being in a less compact urban fabric where the courtyard building becomes more exposed to the solar radiation and as a result, having higher heat gain during the day time. The decrease in its efficiency depends on how much heat will the building gain during the daytime. To a specific extent, it might become less efficient than the other housing patterns. However, having high insulation level, as what has been considered in this research, might help to keep the heat gain in the minimum rates and enable the courtyard building to keep a sufficient level of thermal efficiency.

This research recommends adopting the courtyard house for the current and future housing developments in the hot regions with considering having compact urban fabric. For future studies, it recommends conducting further studies on testing and quantifying the courtyard pattern thermal performance. A special consideration should be given to determining the impact of each of its elements and environmental strategies to help in developing this pattern to have more efficient and comfortable buildings.

Acknowledgements

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The effects of veranda space on indoor thermal environments in Dutch colonial buildings in Bandung, Indonesia

Muhammad Nur Fajri Alfata[1], Tetsu Kubota[1] and Arif Sarwo Wibowo[2]

[1] Graduate School for International Development and Cooperation (IDEC) – Hiroshima University, 1-5-1 Kagamiyama, Higashihiroshima, Hiroshima 739-8529, Japan.
Correspondence email ariel.alfata@puskim.pu.go.id;
[2] School or Architecture, Planning and Policy Development, Bandung Institute of Technology, Jalan Ganesha, Bandung, Indonesia.

Abstract: This study investigates the detailed thermal environments in the existing Dutch colonial buildings in Bandung, Indonesia through field measurements to find out the embedded passive cooling strategies, focusing especially on the effects of veranda spaces. Major thermal parameters were measured at 1.1 m above floor in the center of selected rooms and veranda spaces of the buildings. The vertical distributions of air temperature were also measured at the same points. The results revealed that daytime indoor air temperatures in the buildings maintained relatively lower values (3.4-5.6°C lower) compared to the corresponding outdoor temperatures due primarily to the thermal mass effect. A large vertical gradient in air temperature was seen in the rooms because of the high ceiling height, which is about 5.3-5.7 m. The high ceiling contributed to maintain lower daytime air temperatures at the occupant's level even when the windows were opened. When a veranda space was enclosed, it played a role as a thermal buffer and daytime air temperature inside was approximately 3.4°C lower than that adjacent to a semi-open veranda space. Meanwhile, the veranda space prevented the direct solar radiation from entering the rooms during the peak hours, while ensuring cross-ventilation.

Keywords: Vernacular architecture, Passive cooling, Thermal comfort, Veranda, Dutch colonial building, Hot-humid climate

Introduction

The Dutch colonial building is considered to be one of the vernacular architecture that still exists until today in Indonesia. Indonesia had been colonialized by the Dutch for more than 300 years since the early 17th century. During the period, at first, the Dutch built the buildings by replicating those in the motherland without considering hot-humid climate of Indonesia. From that time, it started to adopt environmental techniques to cope with the local climatic conditions (Widodo, 2007). As such, a number of studies on the Dutch colonial buildings in Indonesia have been carried out to date, but intensive studies on their thermal environments are still limited. This study aims to investigate the detailed indoor thermal environments of Dutch colonial buildings in Bandung, Indonesia and to analyse the embedded passive cooling strategies based on the results of field measurements, with an emphasis on the effects of veranda space on indoor thermal environments.

Bandung is the capital of West Java province with the total population of 2.5 million and the population density was 14,768 people/km² as of 2014 (Badan Pusat Statistik, 2015). Since its establishment in 1811, Dutch built a lot of buildings with various architectural styles in the city. As reported, about 1,500 Dutch colonial buildings still exist in Bandung alone (Nurfindarti and Zulkaidi, 2015). Bandung is located on the highland (approximately 760m above sea level), and therefore the climate is relatively cool. The monthly average temperature is recorded around 22.5-24.2°C, while the monthly average relative humidity ranges from 53-83%.

Methods

Case study Dutch colonial buildings

Two Dutch colonial buildings were selected for case studies through classifying the existing colonial buildings in terms of the building form and building usage. Field observation was also conducted to take their environmental designs into account in the selection. Only free-running buildings were chosen in the selection. As a result, the two buildings were selected, namely Case 1 and Case 2 (Figure 1).

Case 1 is a two-storey school building constructed with timber for the main structure and brick and lime cement for the walls (approximately 40 cm thick). The front façade is facing the north, whereas a large veranda (3.35 m width) is located on the opposite side (south). The veranda on the ground floor is enclosed while it is semi-open on the first floor. The doors facing verandas are louver doors (permanently open) while upper ventilation openings are placed above some of the windows/doors. Meanwhile, Case 2 is a single-storey school building with large verandas on both sides. It is an L-shape building with the front façades facing west and south. The main structure is concrete, while brick and lime cement are used for walls with the thickness of approximately 28 cm. The width of both verandas is 3.0 m and they are well shaded by long eaves. As seen in Case 1, the upper ventilation openings are also placed above some of the windows/doors. Both buildings were occupied by students and teachers during weekdays.

Procedures of field measurement

Field measurements were carried out during the hottest period of the dry season in Bandung, from August to October 2015. In Case 1, the measurements were conducted in two class rooms (Rooms 1-1 and 1-2) (Figure 2a). These rooms are located at the same position between the north-facing front façade and the rear veranda, but on the different floor (Room 1-1: ground floor/GF, Room 1-2: first floor/1F). Room 1-1 is slightly smaller than Room 1-2 in size (80 m^2 and 91 m^2, respectively). Both rooms have high ceilings (5.5 m and 5.7 m) with large windows on both sides of the rooms. Meanwhile, the measurement in Case 2 was carried out in one of the office rooms (Room 2-1) located in between the two verandas (east- and west-facing). Room 2-1 has a floor area of 64 m^2 with the ceiling height of 5.3 m (Figure 2b).

Major thermal parameters including air temperature, relative humidity, wind speeds and globe temperature were measured at 1.1 m above floor in the center of rooms and verandas of the buildings, respectively. The vertical distributions of air temperature were also measured at the same points (see Figure 2). The measurements were conducted under the occupied conditions. During the field measurements, daytime ventilation was adopted over weekdays while night/full-day ventilation was applied over weekends. Occupancy and window/door opening conditions were recorded. Outdoor thermal conditions were recorded by a weather station located in the measurement sites.

In addition, a brief questionnaire survey was conducted to the students in Rooms 1-1 and 1-2 respectively during the same measurement period to investigate their perceived thermal comfort conditions. Thermal sensation, thermal preference, and thermal comfort,

Figure 1. View of the selected buildings, (a) Case 1 and (b) Case 2.

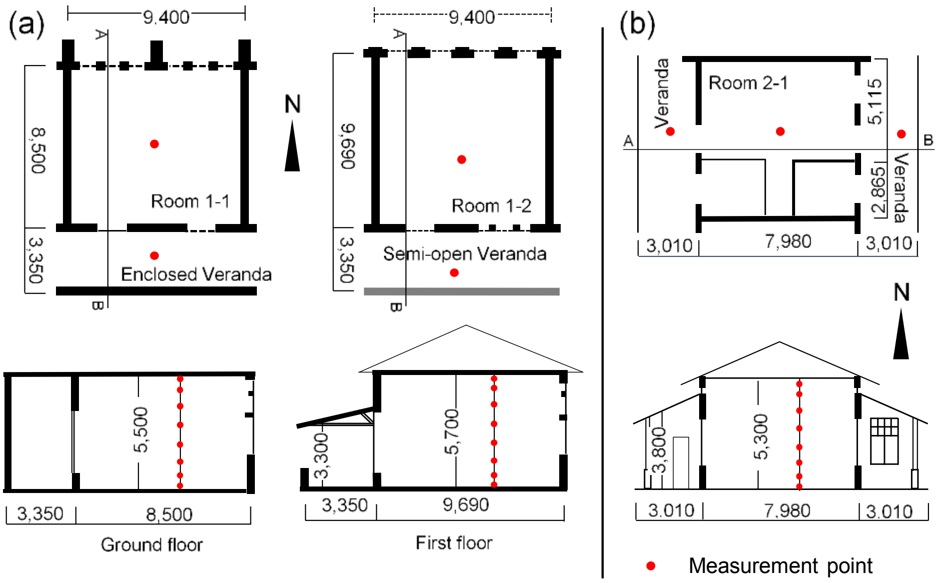

Figure 2. Floor plan, sections and measurement points of (a) Case 1 and (b) Case 2.

etc. during morning class time (07:00-11:00) and afternoon class time (12:00-15:00) were asked using a questionnaire form at the ends of the respective periods.

Results and discussion

Indoor thermal environments

Figure 3 presents the temporal variations of measured thermal parameters in the rooms, verandas and outdoors in the two cases, while Figure 4 shows the statistical summaries of air temperature measurements, under different ventilation conditions. As shown, outdoor air temperature ranged from 18.2 to 32.8°C with the average of 25.1°C, while the outdoor relative humidity ranged from 16 to 97% during the measurement periods. The daily global horizontal solar radiation measured at 11.6-26.3 MJ/m^2. Average outdoor wind speeds in the two cases were approximately 1.1 m/s (measured at 12.6 m above ground level). Rooms 1-1 and 1-2 were occupied with about 30-35 students during the school time, while that of Room 2-1 was less than 10 people (office workers).

Figures 3 and 4 show that indoor air temperature profiles are largely different between the floor levels (i.e., between Rooms 1-1 and 1-2) rather than those caused by various ventilation conditions. As shown, daytime indoor air temperatures on the ground floor (Rooms 1-1) obtained lower values (2.4-5.6°C lower than the outdoors) than those of the first floor (Rooms 1-2) (1.6-3.4°C lower), regardless of the ventilation conditions. Meanwhile,

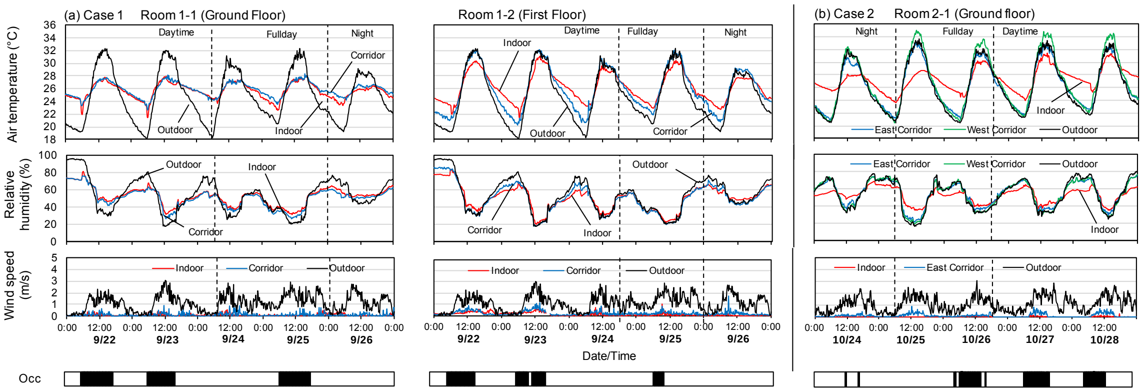

Figure 3. Temporal variations of thermal parameters in (a) Case 1 and (b) Case 2 under different ventilation conditions.

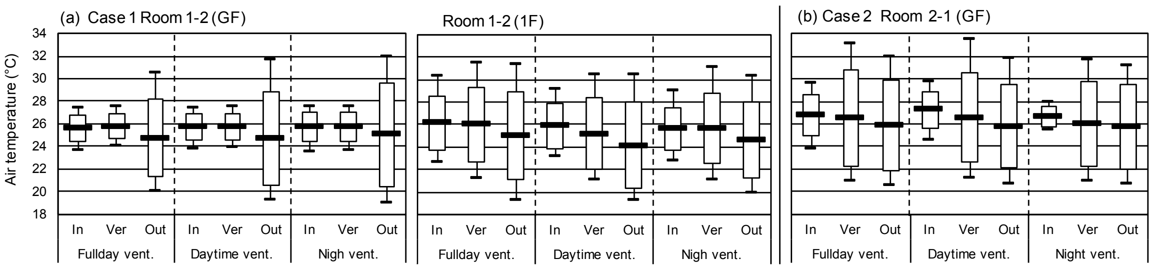

Figure 4. Statistical summary (5% percentile, average, 95 percentile and average ± standard deviation) of air temperatures in (a) Case 1 and (b) Case 2 under different ventilation conditions.

nocturnal indoor air temperature profiles show the opposite patterns, particularly in Case 1: indoor air temperatures on the ground floor are rather higher (4.1-6.2°C higher than the outdoors) than those of the first floor (2.5-5.0°C). These differences are not only due to the floor levels but also due to the difference in the veranda types (enclosed/semi-open verandas).

Overall, indoor air temperatures in the room adjacent to the enclosed veranda spaces (Room 1-1) maintained narrow diurnal temperature ranges compared to those of the corresponding outdoor temperature even when the windows/doors were opened for the whole day (i.e., full-day ventilation). In fact, as indicated in Figure 3, the measured wind speeds in the Room 1-1 during daytime were lower and almost absent (up to 0.2 m/s) compared with the rooms adjacent to the semi-open verandas (i.e., Rooms 1-2 and 2-1) with wind speeds of up to 0.5 m/s (see Figure 8). This is simply because the enclosed veranda discouraged the cross ventilation in the adjacent room (Room 1-1). On the other hand, air temperatures in the semi-open verandas closely followed the corresponding outdoor air temperatures, resulting in the increase in daytime air temperature in the adjacent rooms (Figure 3). But still, the diurnal ranges of indoor air temperatures particularly in Room 2-1 was narrower than those of the outdoors mainly due to thermal mass effect of the building: the thermal mass of Cases 1 and 2 calculated at 2,819 and 2,685 kg/m², respectively.

Thermal effects of veranda spaces

Figure 5 shows the correlations between indoor, veranda and outdoor air temperatures in all the rooms under the different ventilation conditions. As shown, air temperature profiles are almost the same between indoor and veranda spaces in Room 1-1 (enclosed veranda) regardless of ventilation conditions, while those profiles are different in Rooms 1-2 and 2-1 (semi-open veranda). Figure 5a indicates that the enclosed veranda space plays a role as a thermal buffer space. It was particularly effective during the daytime, although it prevented

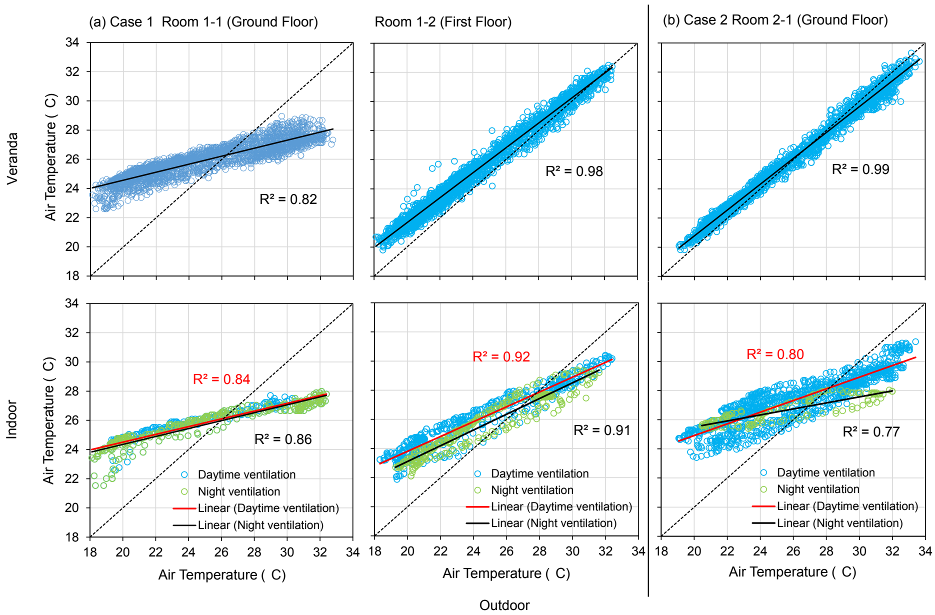

Figure 5. Correlation between veranda, indoor and outdoor air temperatures in (a) Case 1 and (b) Case 2 under different ventilation conditions.

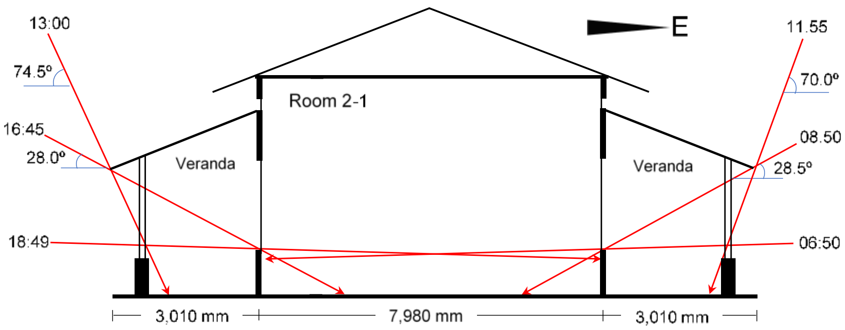

Figure 6. Illustration of solar radiation through the windows in Case 2.

the heat from releasing during the night-time when it was enclosed. However, even if it is a semi-open veranda such as those for Rooms 1-2 and 2-1, the indoor air temperature adjacent to the veranda was not as low as the outdoors at night due primarily to the thermal mass effect (Figure 5).

Nevertheless, the semi-open veranda is effective to improve cross-ventilation while shading. As shown in Figure 6, although Room 2-1 is facing both east and west, the long eaves of veranda spaces prevent solar radiation from entering indoor spaces, and thus the indoor air temperatures maintained relatively lower values than the outdoors even during daytime (Figure 5). As shown, the Room 1-2 received the direct solar radiation through the windows for about two hours during the morning period (6:50-8:50) and for about two hours during the afternoon period (16:45-18:49).

Figure 7 shows vertical distributions of air temperatures in the two cases under the different ventilation conditions, i.e. daytime ventilation and night ventilation. Overall, the ceiling surface temperatures during the daytime in Rooms 1-2 and 2-1 obtained higher values than those in Room 1-1 simply because the former was situated below roofs. Both roofs and ceilings were not insulated in the two buildings and heat was transmitted to the rooms below. The vertical temperature gradients are evident even in the Room 1-1. The temperature gradients seen in these rooms are attributed not only to the transmitted heat from the ceilings,

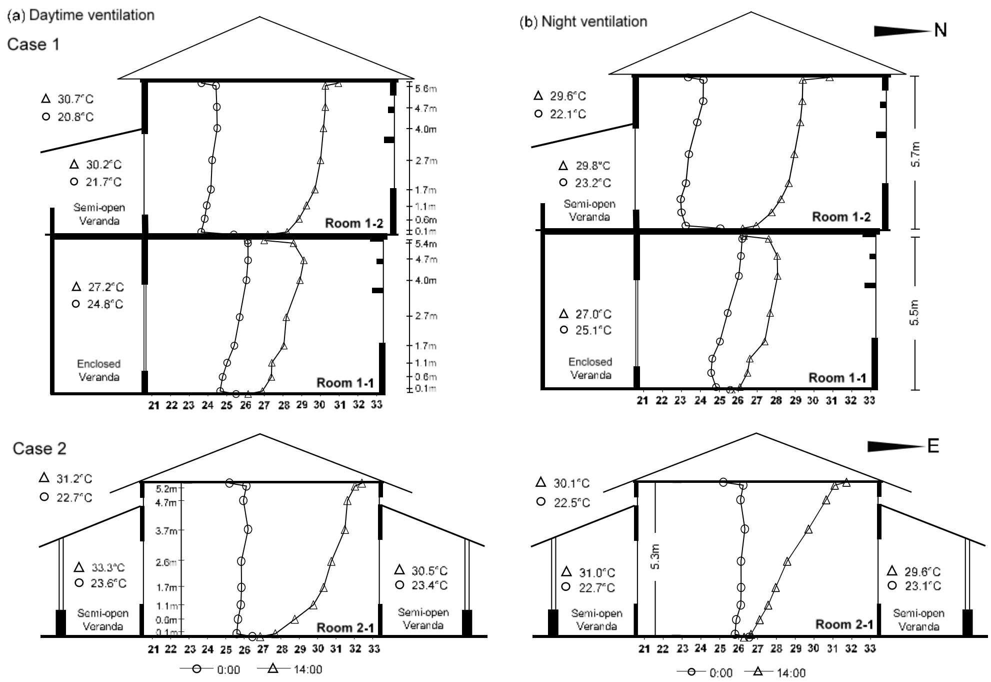

Figure 7. Vertical distribution of air temperature in Case 1 and Case 2 under (a) daytime and (b) night ventilation conditions.

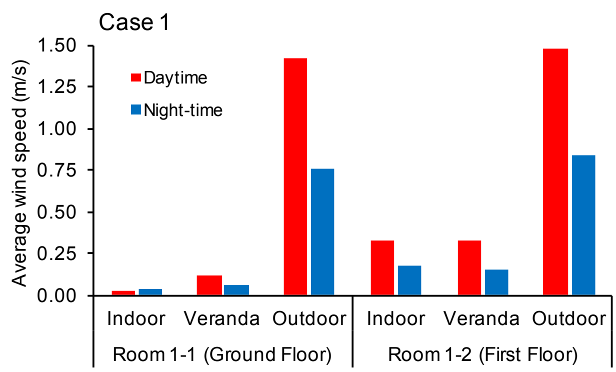

Figure 8. Average daytime and night-time of wind speeds in Case 1.

but also to the high ceilings (5.3-5.7 m). It should be noted that indoor air temperatures at the occupant's level (around 1.1 m above floor) maintained relatively lower values (approximately 27.4-29.8°C) even when windows/doors were opened during the daytime. This implies that a high ceiling would contribute to maintain relatively lower daytime air temperature even when the windows/doors are opened during the daytime (i.e., daytime ventilation).

Figure 8 indicates the average wind speed during the daytime and night-time in Rooms 1-1 and 1-2, respectively. As shown, the average wind speeds during daytime and night-time in Room 1-2 were relatively higher than those in Room 1-1. This implies that cross ventilation was ensured by the semi-open veranda in Room 1-2 (even when windows/doors were closed during the daytime). This is because there were permanent ventilation openings and louver doors above the doors as described before.

Thermal comfort assessment

Indoor thermal comfort was indexed by using the operative temperature (OT) and SET*. Furthermore, the thermal comfort was evaluated by the Adaptive Comfort Equation (ACE)

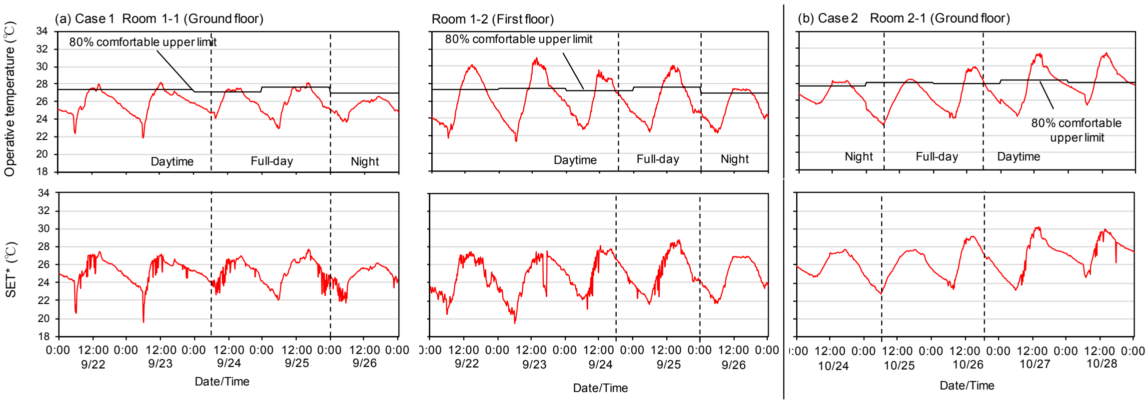

Figure 9. Thermal comfort evaluation using operative temperature (OT) and SET*.

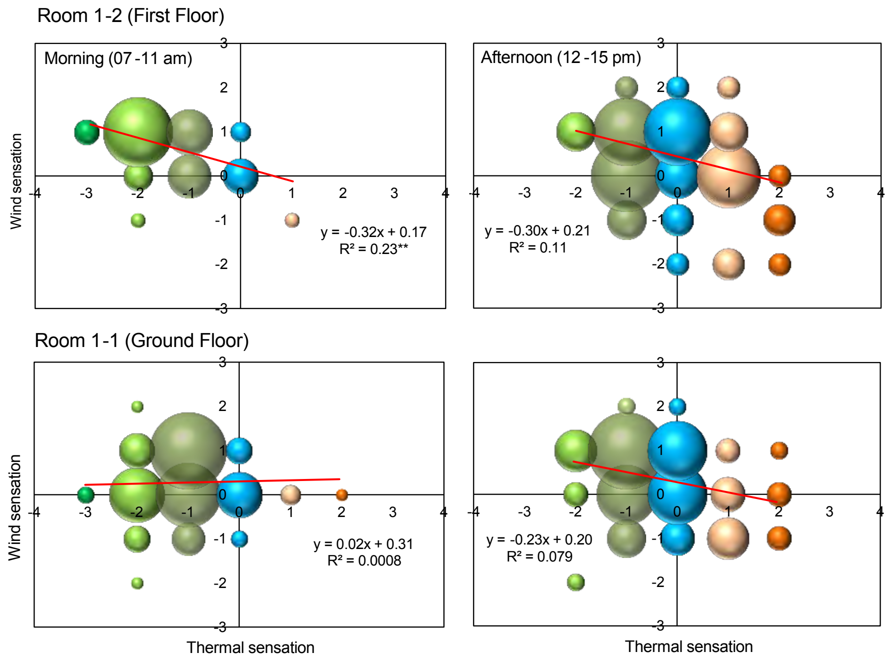

Figure 10. Relationship between thermal sensation and wind sensation in Rooms 1-1 and 1-2.

proposed by Toe and Kubota (2013) for OT. Figure 9 presents the evaluation results of indoor thermal comfort in the three rooms by the two indices, respectively. As shown, during most of the periods, OT in Room 1-1 does not exceed the 80% upper comfortable limit regardless of ventilation conditions. Meanwhile, in the other rooms (Rooms 1-2 and 2-1), OT exceeds the limits during most of the daytime periods. Nevertheless, if the sweat evaporation effect is taken into account by using SET*, the resulting SET* values in Rooms 1-2 and 2-1 become 0.8-2.1°C lower than the corresponding OTs. As previously described, these rooms received slightly higher wind speeds during the daytime. This means that indoor thermal comfort was improved by the sweat evaporation induced by the increased wind speeds from the semi-open veranda. Permanent openings (or louver doors/windows) are also important to let winds enter the rooms even during daytime.

From the questionnaires, a total of 206 responds were obtained for the morning survey, while 154 responds were collected for the afternoon survey. Figure 10 presents the relationships between wind sensation and thermal sensation in Rooms 1-1 and 1-2, respectively. As shown, during both periods, significant relationships can be seen only in Room 1-2 (adjacent to the semi-open veranda). As the wind sensation increases (when they feel stronger winds), they tend to feel cooler. As previously discussed herein, this result also proves that thermal comfort in Room 1-2 was improved by the increased wind speed due primarily to the cross ventilation improved by the semi-open veranda.

Conclusions

The selected Dutch colonial buildings maintained relatively low daytime indoor air temperatures compared to the corresponding outdoor temperature mainly because of the thermal mass effect. Both roofs and ceilings were not insulated and therefore the rooms located on the top floor observed relatively higher air temperatures. The thermal comfort evaluation results showed that indoor thermal comfort, particularly that in the rooms adjacent to the semi-open verandas, was improved by increased wind speeds during daytime. Even when the windows and doors were opened during the daytime, the indoor air temperatures maintained low values at the lower occupant's level due primarily to the high ceiling, which was approximately 5.3-5.7 m.

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Performance of Passive Design Architecture Application in Hot and Dry Climate. Case study: Cairo, Egypt

Nissa Aulia Ardiani[1] and Mochamad Donny Koerniawan[2]

[1] Architectural Design Research Group, Department of Architecture, School of Architecture, Planning and Policy Development, Institut Teknologi Bandung, Bandung, Indonesia, nissaardiani@gmail.com;
[2] Building Technology Research Group, Department of Architecture, School of Architecture, Planning and Policy Development, Institut Teknologi Bandung, Bandung, Indonesia, donnykoer@gmail.com;

Abstract: Various passive design strategies to attain environment thermal comfort in the building project in one of the capital city in hot dry climate region are designed and examined by using Autodesk Ecotect software. Cairo in Egypt, Africa was selected as site location because of the renowned passive architecture design strategies which have been applied since the ancient times. Natural ventilation, passive solar strategies, thermal mass, and evaporative cooling are the main strategies that will be used in this project. *Mashrabiya*, *malqaf*, and *shuksheika* were modified and applied in the building. After the model was simulated, compared to any other strategies, thermal mass and evaporative cooling have a higher impact to enhance thermal comfort. Cairo has unique weather conditions due to its location near the desert, but Nile river nearby helps to provide humidity. Stage of building design to achieve better performance building consists of several phases. First, understand weather condition, analyzing vernacular architecture in the region, designing the architectural idea, simulating the model in the software, analyzing the result, and lastly is decide the best alternative design and materials.

Keywords: passive design architecture, thermal comfort, building performance

Introduction

Cairo as a capital city of Egypt is one of the largest city in the Middle East. Known as mega-cities, Cairo is now facing the thriving of energy problem (El-Gamal, 2014). Many modern buildings not using passive design architecture and as a result, they tend to use mechanical ventilation and cooling devices to reduce heat in the summer which caused a large amount of energy consumption. Whereas, Egypt has vernacular architecture from the ancient times to deal with the harsh weather of Egypt. Passive design architecture such as natural ventilation, passive cooling, evaporative cooling, and thermal mass has been used by utilizing natural energy resources (sun, wind, and water).

Literature Review

From the ancient time, Egyptian vernacular architecture has been dealing with the characteristic of weather in hot and dry climate. Primary techniques were applied to achieve human comfort inside and outside the building. The utilization of building orientation, building material, building color, roof structure, openings, and ventilation are effective to reduce the ambient temperature inside and around the buildings.

Building Orientation

Considering the sun position and prevailing wind when designing building orientation is important. In accordance with Hassan Fathy's studies, slight overhang in the window will block sun radiation in summer and allow them to pass the building in winter to provide heating (Fathy, 1986). From this study and the solar simulation, west and east façade should have less opening because the altitude of the sun is lower in the morning and afternoon which causing the wall received higher solar radiation. Therefore, north-south orientation for the longest façade is preferable in hot and dry climate region.

Building Material

In the traditional architecture of Egypt, natural building materials with a low value of thermal conductivity and high thermal mass were used to control heat and cold weather. Bricks and mud with high thickness is the most widely used material in vernacular building in this region. Reducing temperature environment in summer and enhancing higher temperature in the winter could be achieved by utilizing thick and heavy wall which have low value of thermal conduction. This is in contrast with this modern time where the trend of the building is using concrete and glass, causing more energy needed to provide heating and cooling in the building. The coefficient of thermal transmittance in hot and dry climate region would be better if it has a value approximately 1.1 kcal/hm^{2}C^0 (Lavafpor, 2011).

Wall Material	Wall Thickness (m)	Thermal Transmittance (kcal/ hm^{2}C°)
Hollow brick block	0.30	1.10
Double-wall brick with holes and 8-cm cavity	2 x 0.12	1.12
Brick wall with holes	0.38	1.03
Sand-lime brick	0.51	1.25
Hollow block sand-lime brick	0.51	1.16
Lime	0.51	1.10-1.35
Concrete	1.00	1.20

Source: (Hassan Fathy, 1986)

Figure 1. Thermal transmittance of various material

Figure 1 shows the thermal transmittance for different wall thickness in various kinds of material used in modern buildings at hot and dry climate region. Besides, insulation also has a better impact into the building because it can delay heat flow. Choice of light color of the building envelope in this region will reflect sun rays and decrease heat transfer into the building and works better than darker color (El-Gamal, 2014).

Ventilation

Ventilation plays an important role to provide a pleasant environment in the building interior. Egypt ancient architecture has applied *malqaf* as wind catcher in order to manage fresh air circulation (Attia et al, 2009 and El-Shorbagy, 2010). Temperature differences could be achieved when prevailing winds comes to *malqaf* and then it goes through the atrium and another room before it goes out to the openings. *Malqaf* also could reduce the sand which come together with the wind because the fewer solid material in *malqaf* compared to another room beneath it (Fathy, 1986). On the other hand, *Mashrabiya* as lattice wood panel has various functions, besides giving privacy, it can control air flow, sunlight, humidity, as well as temperature (El-Gamal, 2014). The air circulation within building that applied all these traditional passive design architectures can be seen in figure 2. Regrettably, the application of *mashrabiya* in modern housing or buildings in Cairo is depleted. They prefer to close the window and implement mechanical cooling devices such as air conditioning.

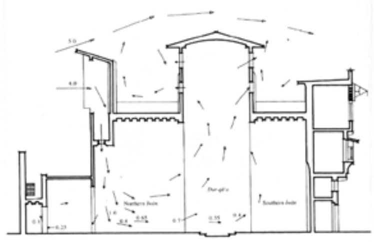


Figure 2. Air circulation concept within building

Evaporative Cooling

Various ways of cooling temperature were applied in hot and dry climate. Water features such as a pond, fountain, and *salsabil* were recognized since ancient time in Egypt to humidify environment and lowering dry bulb temperature (El-Gamal, 2014, Mahmoud, 2011, and Lavafpor, 2011). To maintain satisfying indoor and outdoor temperature in the region which has wide range weather is not an easy task. Several studies were conducted and one of the most influential technique is adding water features in the roof. Studies by Eduardo Kruger, Eduardo Gonzalez Cruz, and Baruch Givoni represent that roof pond is advantageous to reduce the temperature in summer and provide more comfort for building occupant (Kruger et al, 2010). Another study by Sahar N. Kharrufa and Yahyah Adil, roof pond has stabilized interior temperature and added fan will enhance evaporation process and diminish cooling loads of the buildings (Kharrufa et al, 2008).

Project Location and Weather Conditions

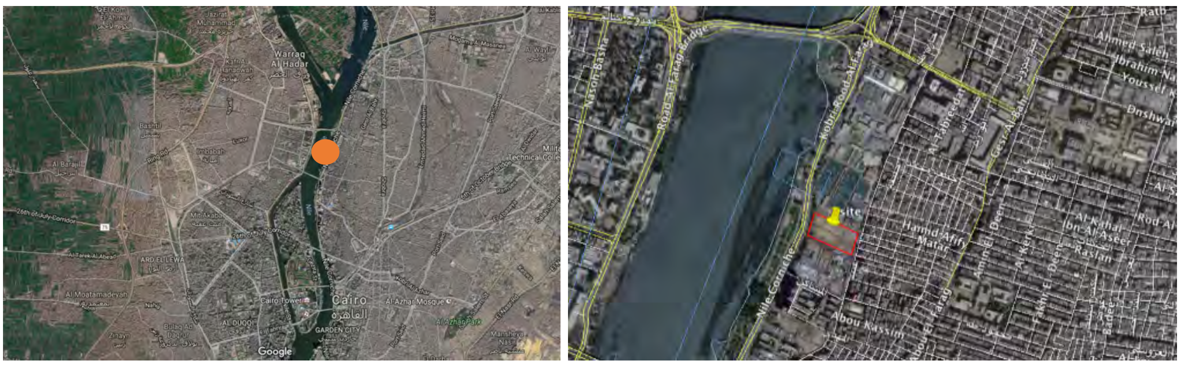


Figure 3. Site Location in Cairo, Egypt

As seen in figure 3, the site of this project is located on the west side of Cairo Governorate in the city of Cairo about 90 m from the Nile River, at the Nile Corniche Road. Cairo is located in (30.05° N, 31.23° E) and classified as BWh Climate Zone, which B is dry climates are characterized by little rain and a huge daily temperature range, W for arid or desert, and h for dry-hot with a mean annual temperature of 18º C in B climates only (Khater et al, 2012). Cairo has two seasons in a year, summer between May and October with temperatures are ranging between 22º C - 35º C on average, and a mild winter from November to April with an average high at around 19 - 29º C during the day but the night the temperature drops dramatically with ranges between 5º C-11º C. In March and April each year, sometimes the hot '*khamasin*' wind with dust and sandstorm blows to the city direction. The mean annual average of solar radiation on a horizontal surface is 876 Wh/s.q.m per hour. Altitude angle at noon in the winter is 33º and in the summer 86º (Al-Shaali, 2002).

Site Plan

In this study, the shape and dimension of the building have been decided which is only the box, but the site plan arrangements need to be studied to respond the location and climate. After did some simulations with CFD and Ecotect to know which layout works best with the ventilation and energy, the site plan layout in figure 4 was chosen. The idea of buildings organization is to make them close to each other so that they can be shading device to the building next to them in the summer and make the space between buildings as a courtyard. Furthermore, because of sun path oriented, most of the south wall will receive a large amount of solar radiation in the winter.

Figure 4. Proposed Site plan

Architectural Design Strategies

Vernacular architecture of Cairo was adapted to this office building to achieve thermal comfort inside and outside the building. North-south orientation building, *mashrabiya* and *malqaf* as natural ventilation, shading devices as passive solar, atrium, *shuksheika*, dome roof, roof pond as evaporative cooling devices, and low thermal conductivity building material were adopted. All these ideas were applied to achieve better thermal conditions and reducing energy demands of the building throughout the years.

Entrance with light structure canopy is on the west side near the main gate of the site (figure 9). In the first floor (figure 5), the north building is public area contains receptionist area with big void and dome roof above, restaurant, meeting point, and toilet. Connected to the south building by outdoor pathway, there is open space office with two meeting rooms. In second floor, north and the south building are connected by a bridge (figure 6). This is a private area which consists of the office area with manager room and meeting room while director room is on the third floor. The section of the building that shows passive designs could be seen in figure 7.

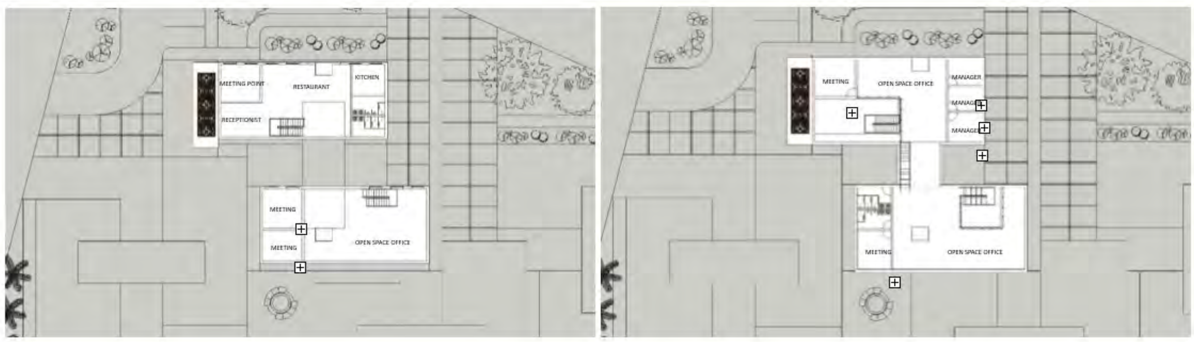


Figure 5, 6. Proposed Floor plan

Figure 7, 8. Building section and Exterior perspectives

Passive Design Application

Mashrabiya panels were placed in all part of façade. In the north wall, to receive prevailing winds, the dimension of the window is bigger than those in the south. Different with a window in north wall, the window has shading device to prevent high amount of solar radiation in summer but receives enough amount in winter (figure 8). The angle of shading devices is 83^{o} in accordance with Hassan Fathy's study about sun altitude. The type of this window was adapted from *mashrabiya* design, which wood material was expected to help lowering the ambient temperature (figure 9).

Figure 9. *Mashrabiya* window detail

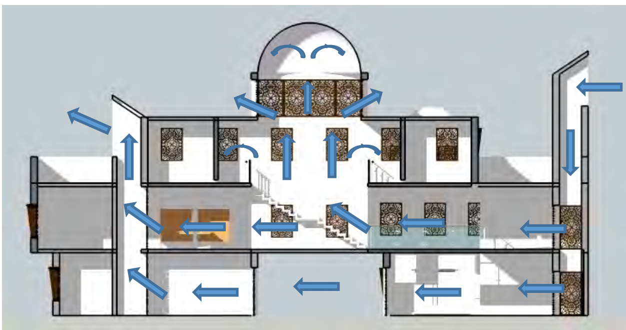


Figure 10. Air circulation within the designed building

Figure 10 above is the diagram of air circulation with the application of atrium, *malqaf*, *suksheika*, and a dome roof in the designed building. It was expected that the wind could penetrate into building with the application of natural ventilation.

Building Material Application

In this studies, building with 3 arrangements of materials was simulated in Ecotect to examine the effect of passive design architecture application as mentioned in the literature review. The first building was using a common material of building in Cairo, 300 mm mud bricks for the walls (figure 11). Double hollow bricks with insulation inside as wall material and window with *mashrabiya* without glass were for the second building (figure 12). And lastly, the materials for the second building were combined with application of roof pond for the third building (figure 13,14).

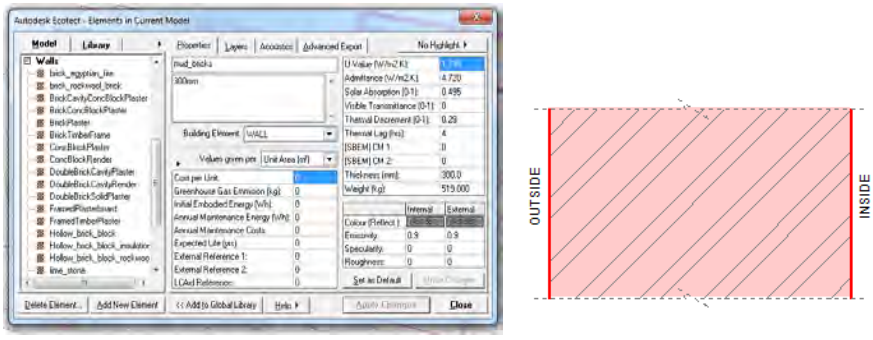


Figure 11. Mud bricks specification for the first building in Ecotect analysis

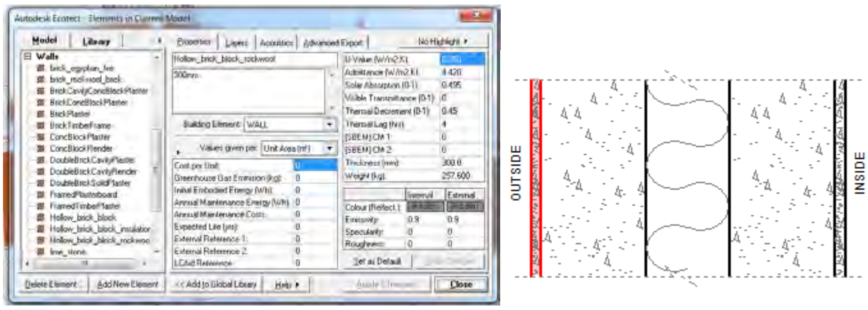


Figure 12. Double hollow brick wall with insulation for the second and third building in Ecotect analysis

Layer	Conductivity (W/m K)	Density (kg/m^3)	Specific heat (J/kgK)
Roof (from inside to outside)			
Prefabricated concrete beam	1.75	2300	920
3 mm Steel sheet	46	7900	454
0.2 mm Polyethylene foil	0.33	1526	1645
30–40 mm Water	0.582	1000	4187
300–900 mm Ventilated air layer	0.026	1223	1063
0.2 mm Polyethylene foil	0.33	1526	1645
200–300 mm Ventilated air layer	0.026	1223	1063
10 mm Polystyrene sheet	0.036	41	1500
0.8 mm Galvanized steel sheet P white	46	7900	454

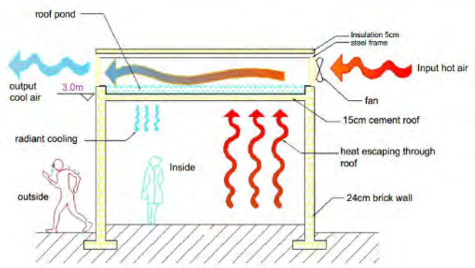


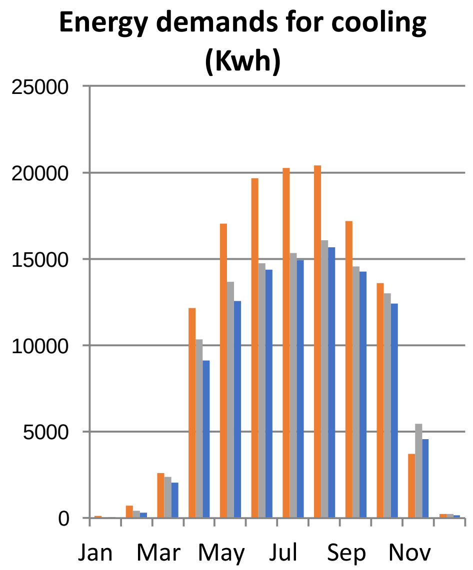
Figure 13, 14. Detail material for roof pond for the third building (Kruger et al, 2010)

Take advantage of water features in the roof was the idea of this building design with the expectation that it will decrease a number of cooling loads and achieve a pleasant environment in the interior compared to the unsatisfying weather outside. Learn from attainment previous study about roof pond, simulation in Ecotect was carried to verify whether the thermal transmittance of water and other material will give a better result. Utilizing fan in the roof will decrease the temperature further because it accelerates evaporation process. However, this fan did not include in the simulation on Ecotect.

Energy Characteristic

The result from Ecotect simulation shows that building with invented material and passive design architecture perform better compared to building with the usual material. Although mud bricks are the sustainable material from Egypt, the invention of technology in building material affecting the performance of the building. In this simulation, the assumption was used that the building using full air conditioning to get the actual energy demands for providing heating and cooling.

From the figure 15, first, second, and third building, consume a total 127,726 kwh, 106,300 kwh, and 100,463 kwh for cooling energy in a year, respectively. August is the peak cooling energy consumption for all these buildings. In the cold season, the energy demands for heating are not as high as for cooling. However, it could be clearly seen in figure 16 that the first building consumes the highest amount of total heating energy in a year of 3,683 kwh, second building of 560 kwh, and third building of 895 kwh. With this result, it could be concluded that the total energy for cooling and heating for the third building which using double hollow bricks with insulation as wall material and window with *mashrabiya* without glass and combined with the application of roof pond is 5.43% less than the second building and 29.65% less than the first building.



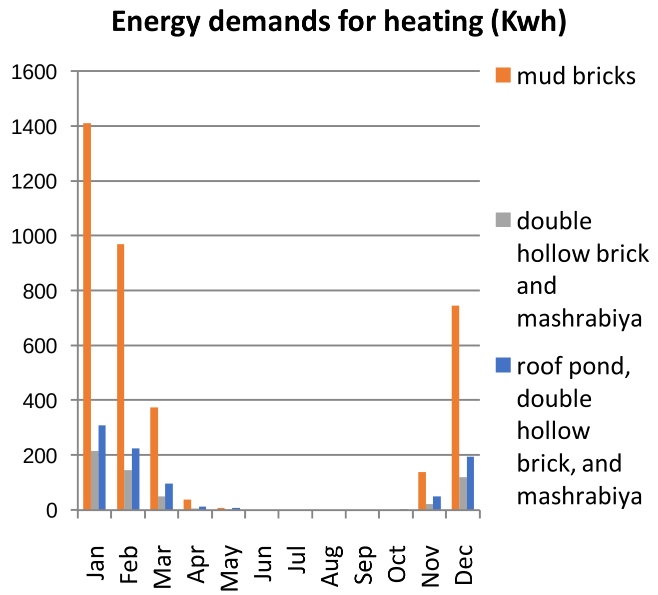


Figure 15, 16. Energy demands for heating and cooling with two alternatives materials and system applications

Conclusions

The design of this office building has been examined by modeling simulation in Ecotect. The result shows that passive design from vernacular architecture, invented with technology give better performance. From Ecotect simulation, energy demand for cooling and heating loads in building using double hollow bricks, roof ponds, and *mashrabiya* panel was lower compared to traditional material. It was because thermal conductivity in this material obstruct outdoor thermal environment coming to the building interior. For future studies, adding water features in *malqaf* would be better because evaporative cooling has proven as an effective technique to achieve comfortable thermal environment, indoor or outdoor.

Passive design for building in hot dry climate can be achieved by implemented these strategies:

- Natural Ventilation: Buildings and trees arrangement to maximize the air flow in the site and courtyard. North – South building orientation and placing evergreen trees in the North sides will caused optimum effects because in Cairo, prevailing winds come from North. Not only shades building, deciduous trees and dense trees in the South side also help to break the winds with sands from South. Large openings should be placed in south side which receive optimum sun radiation in winter. However, the west part of the building should be considered more as solar radiation increased during summer. The courtyard also has a great influence to provide thermal comfort.
- Using elements of traditional architecture concept in Cairo. For instance, *Malqaf* as a prevailing wind catcher and blows the air down to building in the interior, *Shesh* to allow

air flow and control sunlight into the building, and the *Taka* which embodies cross ventilation in the building. Using *Mashrabiya* as an air and light controller, decrease ambient temperature and increase humidity inside the building.

- Direct and Indirect Evaporative Cooling: Using water features in open space to add moisture to the air on the site, such as ponds in the garden and fountain in the courtyard. As a good modifier of micro-climate, water lifting large amounts of heat in the evaporation process to maximize cooling. Beside that, roof pond also could be used to decrease indoor temperature and energy demand for cooling and heating.
- Thermal mass effect strategies, using building material and structure such as thick walls and sandstone which can store heat and provides inertia against temperature fluctuation (Haglund et al).

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The study of thermal comfort conditions as a tool in the early design stage of sustainable school buildings

Kleo Axarli[1] and Maria Kostoula[1]

[1] School of Architecture, Faculty of Engineering, Aristotle University of Thessaloniki, Greece, axarli@arch.auth.gr, kostoula.m@gmail.com

Abstract: It is well known that the school environment has a significant impact on educational activities. There is a strong correlation between the inside environmental conditions and the health and academic performance of pupils. This paper presents a method, developed to be used in the early stages of school building design process, based on the evaluation of thermal comfort conditions according to the climate. The research focuses on Mediterranean climate conditions, specifically those of Greece. Therefore, psychrometric charts of representative cities of Greece, with the most distinctive climatic differences, were examined. The appropriate strategies, defined by the analysis, resulted in the formation of a prototype design for classrooms block that creates thermal and visual comfort conditions, while providing good quality indoor air.

Keywords: school, thermal comfort, psychrometric charts

Introduction

The increasing concern of the indoor school environment has raised the environmental issues related to building design, of prime importance.

It is well known that buildings' climate responsive design moderates the indoor climate for human wellbeing, results to energy conservation and finally to a sustainable design. For school buildings, it is even more important. Thermal and visual comfort, the daylight and sunlight in classrooms and the adequate ventilation are important parameters that affect health, emotions, and academic performance of the pupils, as well as the energy consumption of the school building (Axarli et al, 2008; Dudec, 2000; Hyde, 2000).

The aim of this paper is to investigate the involvement of environmental parameters in designing school buildings and to suggest the design of a classrooms block, which corresponds effectively to different climatic conditions in Greece.

Prevailing climatic conditions in an area, concerning air temperature, determines the length of heating and cooling period and of the transitional periods with very low heating and cooling loads. At the same time, air temperature along with relative humidity are the main climatic parameters influencing design decisions in terms of the quantity of available thermal mass, the degree of thermal insulation, the need for shading and the appropriate cooling system, in order sufficient ventilation, heating and cooling in the school building is provided.

Psychrometric charts are valuable tools for defining the thermal comfort conditions in a place, throughout the year and the potential design strategies for extending the thermal comfort zone (Lechner, 2001). Psychrometric charts drawn for the different seasons of the year of selected Greek cities, provide qualitative feedback as to the potential effectiveness of a given design strategy for the classrooms concerning the architectural synthesis and the envelope configuration, while achieving thermal comfort. The selected design strategies based on the study of psychrometric charts are also evaluated on the basis of visual comfort and indoor air quality conditions created, which are crucial parameters for the school environment.

The time and the requirements of the schools' operation in Greece are worth mentioning. Occupation period is from September to June, Monday to Friday, from 8:00 to 16:00h. The requirements for the indoor environment of school buildings are specified in the following table considering the Greek and the international standards.

Table 1. Thermal -Visual Comfort and Air quality requirements for classrooms.

Thermal Comfort
Recommended conditions of thermal environment in school buildings

	Heating period	Cooling period	
Operative Temperature	min. 20^{o}c	max . 26^{o}C	TOTEE 20701-1(2010), EN15251(2007)
Temperature range	20-24^{o}C	23-26^{o}C	EN15251(2007)
Occupied set point	71^{o}F(21,6^{o}C)	74^{o}F(23,3^{o}C)	ASHRAE(2011)
Relative Humidity	35%	45%	TOTEE 20701-1(2010)
	Dehumidification when RH>60%	Humidification when RH<25%	EN15251(2007)

Air Quality
Minimum ventilation rates (airflow/person)

22 m3/h/per	TOTEE 20701-1(2010)
7 L/s/per	EN15251(2007)
6,7-7,4 L/s/per	ASHRAE 62.1(2016)

Visual Comfort
Recommended Illuminance levels

300 lux	TOTEE 20701-1(2010) EN12464-1(2002)
30-50fc	IES The Lighting Handbook (2011)

Climate in Greece and thermal comfort analysis

Generally speaking, Greek climate is a temperate climate characterized by its cold, humid winters, hot and dry summers and the four distinct seasons. Winter temperatures often fall below freezing point and summer temperatures can reach 40^{o}C, while the amount of insolation is significant in all places. However, the diversity of landscape, the vicinity with the sea and the existence of mountains and rivers influence a lot the local climate. A wide range of climatic types can be found across the country.

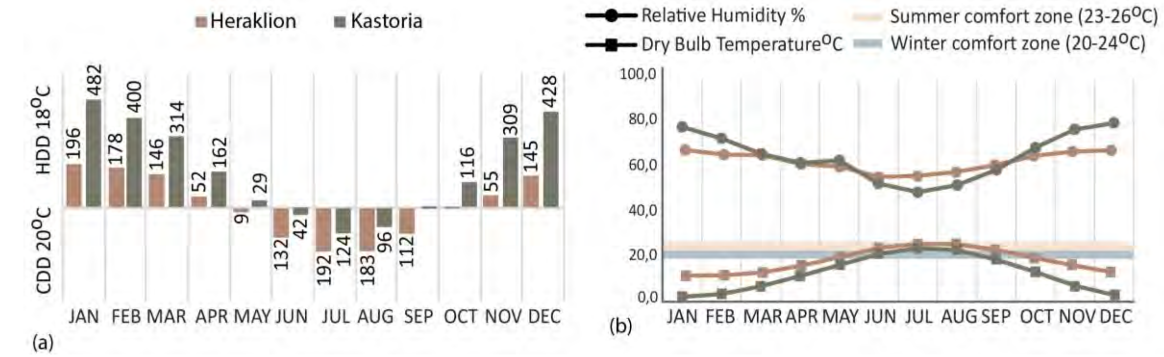


Figure 1. (a)Heating Degree Days 18^{o}C, Cooling Degree Days 20^{o}C of Heraklion and Kastoria and (b)Warm zone (Heraklion) and cold zone (Kastoria) Climate Conditions.

According to Heating Degree Days, Greece is divided in four climatic zones. This research focuses on A and D climatic zones, the warmest and coolest one respectively, as they are considered representatives of the variety of Greek Climate and it examines the climatic conditions of the two cities, Heraklion and Kastoria accordingly. The climate of Heraklion (lat. 35,20^{o} long. 25,11^{o}, alt. 39,3m -zone A) is characterized by high temperature and sunshine in summer, while the climate of Kastoria (lat. 40,27^{o}, long. 21,17^{o}, alt. 660,9m -zone D) by low temperature with periodically severe cold winds in winter.

The monthly calculation of Heating Degree Days determines the months of the heating period which are November to April for Heraklion (A' Zone) and October to April for Kastoria (D' Zone). Cooling period includes July and August for both cities, while transitional periods include September, October, May and June for Heraklion and September, May and June for Kastoria (Figure 1). The annual fluctuation of average monthly air temperature and relative humidity is more intense in Kastoria than in the warm city of Heraklion. In summer, the levels of average air temperature are within the predicted limits of acceptable thermal environment in both cities, while in winter the significantly low temperature observed in Kastoria, results in increased heating load. The variation of humidity levels appears to be bigger in Kastoria, due to high rainfall, than in Heraklion, which is mostly characterized by dry conditions and less rainfall (Figure 1).

Thermal Comfort Analysis of Greek Climate Zones

Using the software "Climate Consultant" © of UCLA Energy Design Tools Group, the warmest and coldest Greek climate zones are analyzed based on an hourly calculation, in order to define the periods with thermal comfort conditions (Figure 2). The potential extension of the thermal comfort zone is investigated by suggesting specific strategies as indicated in Givoni and Milne bioclimatic chart. The analysis takes into account clothing 1.0 clo for winter and 0.5 clo for summer and metabolic rate 1.2 met (ASHRAE 55, 2009).

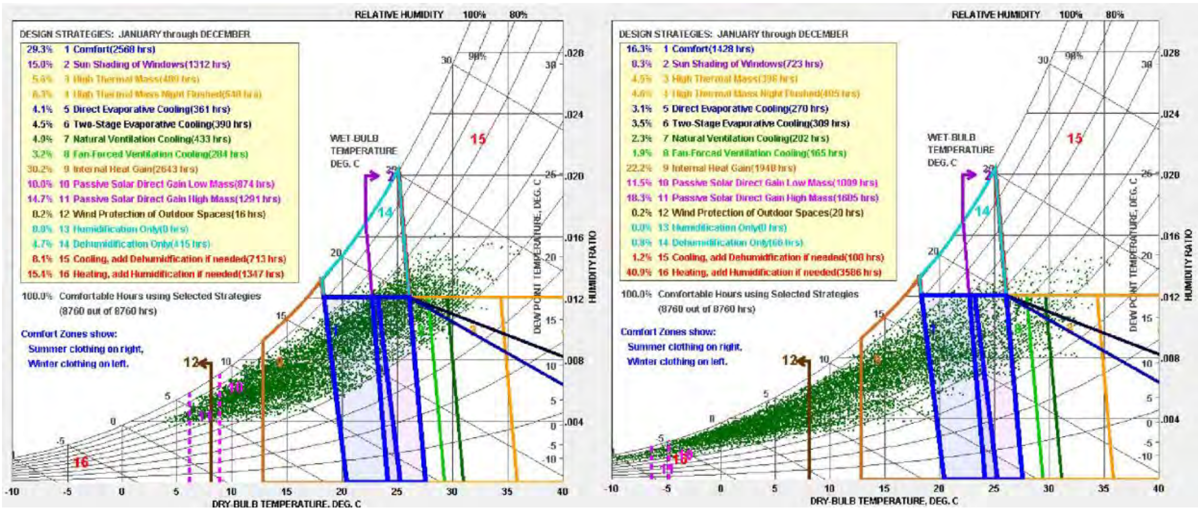


Figure 2. Psychrometric charts of Heraklion (warm zone) and Kastoria (cold zone)

In the warm zone (Heraklion), it is observed that in prolonged periods of time, especially during the transitional periods, thermal comfort conditions exist (Figure 3-a). Pupils in the warm zone experience more hours in thermal comfort conditions during the annual school operation than in the cold one. On the contrary, in the cold zone (Kastoria), the lower air temperatures cause noticeable discomfort conditions during winter while comfortable conditions exist during summer school break (Figure 3-a). It seems convenient enough to prolong school operation in summertime in both zones especially in the cold one.

Due to high levels of occupancy in classrooms, the internal heat gains can cause a considerable air temperature increase thus lowering the heating loads in both zones especially in warm zone (figure 3-b). Their effect depends on the airtightness of the building envelope and the level of thermal insulation, but as the internal gains are related to metabolic activity, good ventilation is essential to remove excessive humidity due to respiration and sweating during the occupancy period. In cold zone, internal heat gains can contribute to the maintenance of thermal comfort during the whole year (Figure 3-b).

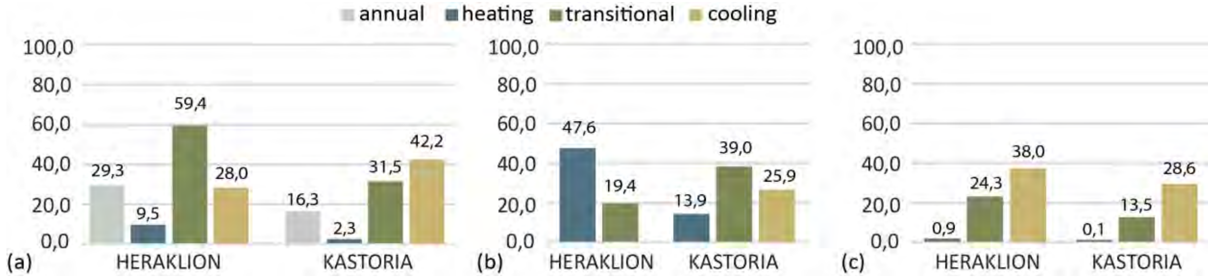


Figure 3. (a)Annual conditions of thermal comfort, expressed as percentage of the total amount of hours and contribution of (b) internal heat gains and (c) sun shading of windows, in thermal comfort

The passive solar heating systems are effective enough to counterbalance the increasing heating loads in both climatic zones (Figure 4-a). Exploitation of solar radiation with direct gain passive solar systems has a strong affect in thermal performance. High mass internal elements can be used effectively to store and distribute solar heat to the classrooms for a significant number of hours in both zones. In the cold zone, it is mostly effective during transitional periods, while in the warm zone can lead to a greater reduction of energy demands. However, the increased heating load in the cold zone enable the low mass structures to be heated immediately, when ambient conditions are favorable. In this case spaces, such as corridors, can be used as thermal buffer zones either providing heat build-up or protecting the main usable spaces from harsh winter conditions. In any case tighter building envelope and high thermal insulation are required.

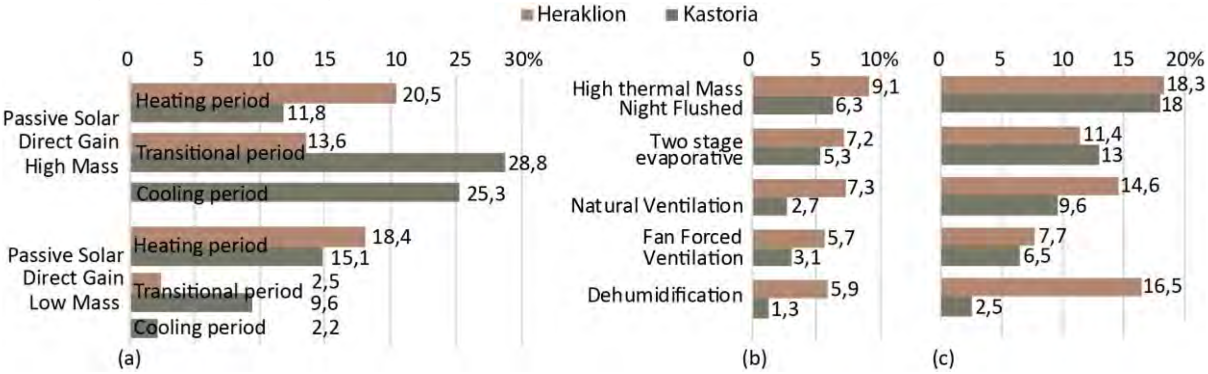


Figure 4. Effectiveness (% of comfortable hours) of (a) Passive Solar Direct Gain heating systems for the whole year, (b) cooling systems for the transitional period and (c) cooling systems for cooling period.

High mass is proven to be highly effective during cooling period, for both zones, while different cooling systems are predominantly effective for the climatic conditions of A’ and D’ zone (Figure 4-b,c). Indirect evaporative cooling systems are more suitable due to low humidity levels in the cold zone. On the contrary natural ventilation seems to perform better in the warm zone due to the higher needs of dehumidification. However, this strategy seems to be less effective during the day when there is high outdoor air temperature. Yet, some advantage can be taken of the low night time air temperature, thus applying night ventilation. Nevertheless, good ventilation is extremely necessary in school buildings because of the high occupancy, as long as discomfort caused by draught is avoided.

Sun shading of windows designed for passive solar heating is mostly important during summer, unlike heating period when solar radiation is welcomed (Figure 3-c). During transitional periods sun shading needs also increase, especially in the warm zone. It is worth mentioning that solar control in order to avoid risk of overheat and glare can be easily managed with shading devices, preferably movable ones, due to solar path in both areas, although the lower sun orbit in Kastoria (23^0 solar altitude angle on 21st of December) during winter should be taken into consideration. However, as shading devices can limit glare together with the amount of light penetration, the level of daylight achieved has to be investigated as well. An adaptive façade configuration is important to provide well-balanced indoor environmental conditions concerning thermal and visual comfort.

Strategies for thermal, visual comfort and good air quality

The analysis of the climatic conditions of the coldest and warmest Greek climatic zones and the discussion on the results of psychrometric charts set a guideline on appropriate strategies to be used in the early design stage for school buildings in Greece (Table 2).

Table 2. Weighting factor of selected strategies applied at the early stage of designing school buildings

Passive Design Strategies	warm zone (A') Heating	warm zone (A') Cooling	cold zone (D') Heating	cold zone (D') Cooling
Passive Solar Systems(low mass)	○		◐	
Passive Solar Systems(high mass)	●		◐	●
Insulation	◐	○	●	●
Airtightness	◐	○	●	●
Solar Control	◐	●	○	◐
Natural Ventilation cooling	○	●		◐
High thermal mass		◐		●
High thermal mass & night ventilation		●		●
Evaporative cooling		◐		●

Active Design Strategies	warm zone (A') Heating	warm zone (A') Cooling	cold zone (D') Heating	cold zone (D') Cooling
Active Solar Systems	◐		●	
Low Energy Conventional Heating systems			●	
Active Cooling Systems		●		○
Heat Recovery Ventilation		●	●	
Dehumidification		●		
Low Energy Air-Contitioning systems		◐		

○ less ◐ more ● most important

Passive Heating and Cooling Systems

South facing glazing is the simplest and most effective solar passive system for school buildings. In the warm Greek climatic zone, windows should be operable, thus undesired heat can escape. In the cold zone, low U-value of windows is essential to eliminate heat loss. In general, passive cooling systems should optimize both, local breezes, which are common in Greece and the available natural sources (water mass, geothermal energy) to support hybrid systems when needed. Using the Adaptive Comfort Model (ASHRAE 55-2010), for thermal comfort analysis, it is clearly defined that there is a significant increase of natural ventilation effectiveness (from 4,9% to 24,7% of the hours in comfort in the warm zone and from 2,3% to 10,4% of the hours in comfort in the cold zone). When occupants are allowed and encouraged to manually control their thermal environment, by means of operable windows and shading systems, their ability to adapt to the indoor conditions increases.

Strategies providing good quality of air

Passive cooling systems in order to compensate for the excessive internal heat gains should be related to sufficient ventilation rate. Levels of occupancy and activity and consequently the need for high ventilation rate have to be taken into consideration so as the selected strategies (i.e. as cross ventilation, fan forced, stack effect) effectively correspond to most adverse conditions. A system combination is ideal as long as it can be supported from building form. For example, a stack effect ventilation system combined with heat recovery is a suitable solution in case of cold climate (as in D' zone) when a compact configuration is appropriate. Roof monitors can also contribute to natural ventilation.

Solar and Light control

Horizontal or vertical louvers and overhangs (depending on orientation), are appropriate shading devices to avoid heat trapping inside the building (Palmero-Marrero et al, 2010). They can also contribute to the distribution of daylight. Shading devices acting as light shelves have a positive effect not only on sun shading but also on daylight distribution inside the classrooms, in the same way as high glazing and glazed roof apertures contribute to daylight uniformity (Antoniou et al, 2006; Axarli et al, 2007). The ability of shading devices to permit or block the solar radiation, distribute the daylight and facilitate natural ventilation provides high building performance and the potential of manual control of indoor environment.

Thermophysical building envelope features
Great thermal inertia of buildings against temperature fluctuations results in high building thermal performance in both hot and cold conditions. Buildings in the cold Greek climatic zone have increased need of high mass, insulation and airtightness in order to keep the collected heat from the sun. On the contrary, in the warm zone, where there is a risk of overheating, movable panels with thermal insulation have better effect. However, it is essential that thermal insulation meets the relevant regulations, in both zones. It is worth mentioning that sufficient and appropriate vegetation improves microclimate conditions thus thermal comfort conditions.

Prototype design for a classrooms block

The aim of the research is the design of a classrooms block taking into account strategies to improve thermal comfort conditions throughout the year, as analyzed above. The proposed prototype design has to fulfill the environmental requirements for both, the cold and warm climatic zones in Greece and to create a thermal and visual comfort environment with good quality air and the minimum heating and cooling load.

The basic design requirement for the fabric is to comply with the Greek Regulation for the energy performance of buildings, i.e. U_m=1.26 W/(m^2.K) for the warm climatic zone and U_m=0.96W/(m^2.K) for the cold zone (the ratio of floor area to volume, is approximately 0,20). The prototype classroom block consists of four classrooms attached to a double height corridor.

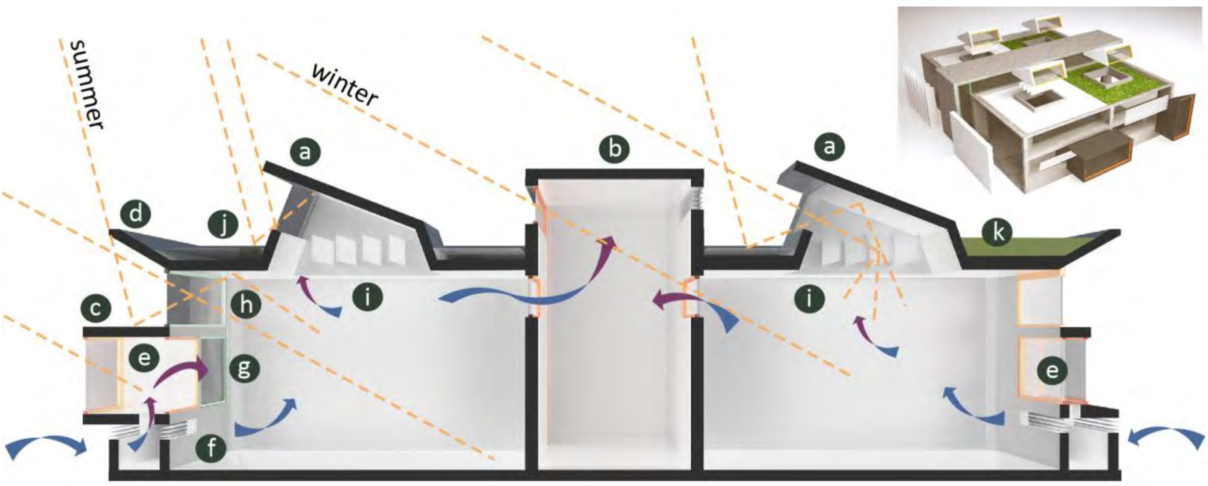


Figure 5. Section across classrooms and corridor and alternative design practices.

Sets of classrooms blocks can develop building wings, preferably along E-W axis so as classrooms will have south or north oriented glazing. The configuration meets Greek regulations for minimum classroom dimensions (7.0m X 7.0m and 3m height). For better daylight penetration the classroom height in the proposed design, is set to 3.9m.

The building is characterized (Figure 5) by south facing, slightly inclined, roof monitors [a] and a raised central corridor [b] so as to provide uniform daylight, ventilation and solar heat benefits avoiding risk of glare. Structural elements of reinforced concrete, form light shelves[c] and inclined overhangs[d] that contribute to solar control. A passive system [e] attached to north and south facades consist of two glass panes with a wide air cavity. It acts as a collector for solar radiation in order to provide preheated air for the south oriented classrooms and as a thermal buffer zone, protecting the northern oriented classrooms from cold outdoor conditions.

The building envelope, made of precast concrete double wall system, offers protection from undesirable environmental conditions (noise, air temperature, wind) and the potential to house systems that assist the envelope environmental functions (i.e. fans for evaporative cooling and ventilation) [f]. Windows are arranged in distinctive zones for view [g] or daylight penetration[h] and with characteristics that meet the requirements for effective thermal performance under Greek climatic conditions. All windows can be manually operated to avoid overheat. Roof monitors are equipped with daylight reflectors[i]. Cool roof [j] and reflective materials are more effective in warm zone, while in cold zone green roof [k] is used as an additional thermal layer.

Evaluation of the prototype design of the classrooms block

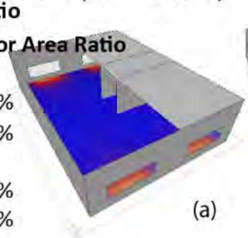
The assessment of the prototype design of the classrooms block refers to the adequacy of visual comfort levels and the ability to use efficiently the ventilation system applied.

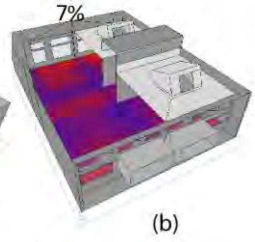
The visual comfort was examined for Heraklion-A' Zone and Kastoria-D' Zone using the Autodesk Ecotect Analysis© 2011 software for urban conditions (see table 3). The percentage of average daylight factor was measured 5,62% and the average daylight level was calculated 449,45lux for Heraklion (warm zone) and 365,18lux for Kastoria (cold zone). Daylight levels meet sufficiently the requirements of at least 250lux illuminance at 75% of the classroom area. The shape of the proposed classrooms block increased the uniformity of daylight distribution and the penetration of daylight to the back space of the classroom, compared to a typical classroom meeting the minimum Greek requirements (Table 3). Although the passive system with the double glazing applied to the proposed design reduces daylight levels, visual comfort is achieved (table 3).

Table 3. Required Fenestration for prototype Classrooms-Block and daylight analysis of (a) the conventional design and (b) the proposed design

Daylight Illuminance Calculation Assumptions	
Time	9:00am & 3:00pm
Date	Spring Equinox (20 March)
External Daylight Illuminance	CIE Overcast Sky Model Heraklion 8000lux Kastoria 6500lux
Daylighted area	75% X(7,0m X 7,0m)
Plane	0,80 above the floor

Fenestration Characteristics	
Window to Floor Area Ratio (According to greek regulations)	10%
Window to Wall Area Ratio (According to greek regulations)	20%
Total Window area to Floor Area Ratio (ASHREE 2011)	7%
View Window to Floor Area Ratio	7%
Daylighting Fenestration to Floor Area Ratio	
South Orientation	
Glazing above light shelves	7-10%
South-Facing roof monitors	6-8%
North Orientation	
High glazing	10-13%
South-Facing roof monitors	6-8%


(a)


(b)

ClassVent© tool, developed by the British Department for Education, was used to investigate the capability of building envelope in allowing the air flow procedure. It is assumed that the average required volume flow is 7lt/sec/ person (equivalent to 25m^3/h/per or to 4ach) so as to meet the standards of Table 1. The analysis proved that the size and the location of ventilation inlet areas and the stack outlet area are efficient, so that air can flow smoothly into the stack (Table 4). Results show that the design of the classroom block and its fabric configuration enhance the natural ventilation; thus, ventilation needs are covered sufficiently without undesirable effects. It is worth mentioning that cross-ventilation compared to stack effect ventilation is more difficult to be applied in school buildings as it demands a higher value of wind speed and a wider range of temperature between indoor and outdoor conditions.

Table 4. Required Classrooms Block ventilation openings' area

Ventilation Openings' area Calculation Assumptions		
Stack Outlet height from ground		6,2m
Front Opening height from floor		0,75m
Number of occupants		30 pupils, 1 teacher
Temperature ^oC (Outside /Inside)	Heraklion	Kastoria
Winter	14,1/19-20*	6,8/19-20
Transitional	22,1/26-27*	18,9/26-27
Summer	26,2/26-27*	23,6/26-27

*accoring to levels of adaptivity (EN15251:2007)

Results	HERAKLION			KASTORIA		
	Heating period	Transitional period	Cooling period	Heating period	Transitional period	Cooling period
Stack Outlet/Façade Opening Areas (m^2) (no wind)	0,37/ 0,32	0,41/ 0,36	0,93/ 0,87	0,25/ 0,21	0,33/ 0,28	0,54/ 0,47
Stack Outlet/Façade Opening Areas(m^2) (wind 3m/s)	0,37/ 0,25	0,41/ 0,27	0,93/ 0,36	0,25/ 0,19	0,33/ 0,23	0,54/ 0,30

Conclusions

This study has taken a step to the direction of studying the quality of the environment in classrooms and revealed that it is important to understand the local environment before being able to develop a suitable climate responsive school building. Extensive research on the particular climate characteristics of a country can lead to the more specific early stage design strategies for school building design. The evaluation of the proposed design strategies applied in the prototype design of the classrooms block has shown that if appropriate design climate matching issues are taken into account in the early stage design process, they can contribute to the creation of space with high environmental quality and good performance in both the warm and cold climatic areas in a temperate climate as those of Greece. Also, when designing in terms of sustainability, understanding the interrelationship between the applied design practices is essential, in order to maintain a balance between thermal and visual comfort.

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The Practice of Architecture in the Tropics: Integrated Design Approach

Nitin Bansal[1], Manit Rastogi[1] and Piya Gupta[1]

[1] Morphogenesis, New Delhi

Abstract: Architecture in some of the densest cities in India (and the world) demands highly conscious spatial consumption with office design standards reaching efficiencies as low as 50sq.ft./person. Consequently, high internal gains and stress on available resources have led to innovative developments in the way these buildings need to be designed and built. Sustainable architecture must not only have a reduced impact on the environment but also needs to be flexible enough to cater to the changing usage of the building over an extended time period. Affordability or cost effectiveness, a key development factor in emerging nations often overrules the intention of sustainability, making it essential for these design strategies to be economically viable too. The critical balance between efficiencies for structure, area, occupants and resources needs to be established right from the conception level. Exploring the potential of adaptive comfort can help realize the possibility of using protected open spaces for user- interactive functions of a programme.
The paper outlines the dynamics of an integrated design approach to practicing sustainable architecture in India, through an office building in Hyderabad. Located in the most prolific climate typologies in India, the design results demonstrate a balance of sustainability, spatial efficiency, economy and occupant satisfaction taking shape into 4 climate-responsive buildings.

Keywords: Energy, Sustainability, Office-Design, Density, Commercial

Background

Practicing environmental architecture in a developing country like India has unique advantages as well as challenges. Vernacular architecture is deeply rooted in passive design while urbanization has led to highly populous cities with 60% of the urban population living in metropolitan cities like New Delhi, Mumbai, etc. This has resulted in overcrowding, lack of space and consequently sky-rocketing real-estate rates equivalent to any other metropolitan city in developed nations. Design efficiency for the built environment is hence crucial and must bring together a comprehensive understanding of the principles of structural flexibility, optimised indoor environment controls, occupant comfort creating a holistic sense of identity for the overall macroclimate. The metrics of Sustainability, Affordability, Identity and

Figure 1.Key parameters for commercial architecture in developing countries

Livability extensively cover both **requirement** and **result** for good architecture, as depicted in Figure-1.

Sustainability and affordability come together to create contemporary and global architecture, yet respond to the local climatic conditions and subtly to our deep rooted socio-cultural instincts. This process of integrated design has been illustrated through an IT-office project in the hot-humid climate of Hyderabad.

Climate

Analysing the climate is the first step towards understanding the possible passive strategies applicable to the site. This process is critical in setting the project parameters for comfort and usability of open spaces. The prevalent tropical climate in India demands a combination of passive strategies for year-round comfort. Considering conventional occupancy for commercial buildings (9am-6pm), the external conditions indicate the potential to employ evaporative cooling strategies for the hot-dry period of the year. Physiological cooling is the most effective strategy for extremely humid situations demanding approaches that utilize the prevalent East-West winds at over 2.5m/s. High intensity of solar radiation adds to the challenge of creating a glare-free, 100% day-lit working environment while ensuring effective solar control (for reducing cooling loads). *The Indian Model for Adaptive Comfort study (Green Rating for Integrated Habitat Assessment* (GRIHA)-Appendix-1, The Energy and Resources Institute, 2015) addresses the thermal adaptability of people living in tropical climate typologies inherent to the country.

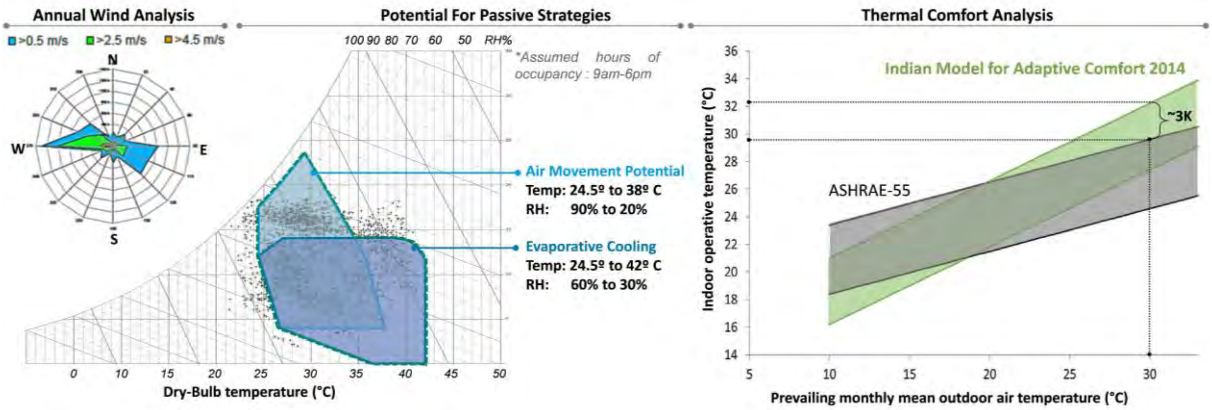


Figure 2. Climate analysis and Thermal Comfort Standards in Hyderabad

Sustainable Design Brief

Historical precedents suggest that architecture itself was a response to lack of availability of resources and response to climate, the principle being that nothing was ever wasted. This approach of 'No is More', i.e., imagining one has no resources at one's disposal, becomes an inspiration for creating truly optimised built-spaces catering to present-day issues of stress on resources. Based on an approach that began with the carrying capacity of the land, the 100 acre site for an IT campus in Hyderabad was found to be capable of sufficing the conventional water demand of 14,400 persons. A 3m deep water reservoir of approximately 14 acres was designed to be located in the low-lying section of the site. The annual energy consumption for the project was targeted at 60kWh/m^2/yr. with primary energy consumption estimated at 35kWh/m^2/yr. and 25kWh/m^2/yr. being load from equipment. Integrating renewable resources to offset the energy demand presented a requirement of a 13 acre solar farm. Comparable spatial requirements allowed the solar farm to be planned on top of the water reservoir, expected to significantly reduce evaporative losses while cooling the solar panels at the same time.

Table 1. Carrying Capacity for water resources.

Site Area	4,09,961	sq.m
Annual rainfall*	0.822	M
Potential annual Rainwater collection (50% run-off, 10% evaporative losses)	**1,68,494**	**cu.m**
Water requirement per day per person**	45	lpcd
Carrying capacity of site based on water demand	**14,400**	**persons**
Size of water reservoir required(@3M depth)	**56,165**	**sq.m (~14 acres)**

*Sources: *www.rainwaterharvesting.org, ** National Building Code-2005*

Table 2. Carrying Capacity for renewable energy

Carrying Capacity (Based on water demand)	**14,400**	**persons**
Total Built-up area required @ 9.29sq.m/person (100sq.ft./person)	133,781	sq.m
Target Energy consumption	**60**	**kWh/sq.m./yr**
Total Annual energy consumption	8,026,830	kWh
Area required for installing solar PVs*	**53,512**	**sq.m. (~13 acres)**

*Sources:*1500kWh energy generated annually per 1kWp of installed capacity, requiring 10 sq.m/kWp.*

Urban Design and Masterplanning

Designing for utilizing prevailing winds, visual comfort through day-lighting and solar control resulted in a series of urban design solutions. 6 schemes were generated without imposing any pre-conceived notions of aesthetics, responding purely to the density and environmental performance targets. The schemes were first analysed through the process of computational fluid dynamics to understand the movement of air in open spaces and the potential to naturally ventilate the buildings. The built-mass was staggered to enhance natural air-movement allowing most facades to be opened-up for natural ventilation. Less deep building floor plates provided good daylighting potential and allowed for natural cross ventilation. Constructional phasing of the proposed development was considered critical for all practical purposes. The resultant was a masterplan translating the sustainable design brief thereby generating a microclimate of comfortable outdoor and semi-outdoor spaces with the potential of being utilised for the interactive common functions of the programme. In order to maximise on the functionality of the courtyards, the effect of introducing a roof, elevated air-speeds and dry mist systems were explored as targeted strategies for open spaces. The PMV (predicted mean vote) prediction model developed by Fanger in 1970 was used as the basis for testing comfort in outdoor spaces as it considers physiological processes of the human body which are crucial in the perception of comfort. The hot-dry period from March-June would require high thermal mass combined with evaporative cooling and elevated air speed for good thermal outdoor comfort. Moreover, shaded and ample natural ventilation along with the use of fans to elevate air speed proved to create good thermal outdoor comfort from July to February. Strategies of evaporative cooling and evapo-transpiration (shade by plants and vegetation) were considered for further enhancing the outdoor comfort conditions. Direct solar control strategies for the courtyard helped almost double the period of comfort during occupancy hours. Enhancing the air-movement by morphology as well as introducing active methods like fans proved to be successful in increasing the hours of comfort to 60%

annually but also increased the capital cost negligibly by £1/sq.ft. Moreover, mist cooling systems drastically improved the microclimate by achieving comfort in 97% of the occupied hours, also adding to the investment by £4/sq.ft. Finally, common functions like the food court seating and even part of the library were designed as semi-outdoor protected spaces encouraging a dialogue between the natural environment and the users, proving applicability of adaptive comfort strategies in hot-humid climate conditions. Using the above processes, over 1,00,000 sq.ft., comprising 9% of the total built-up area, was successfully eliminated

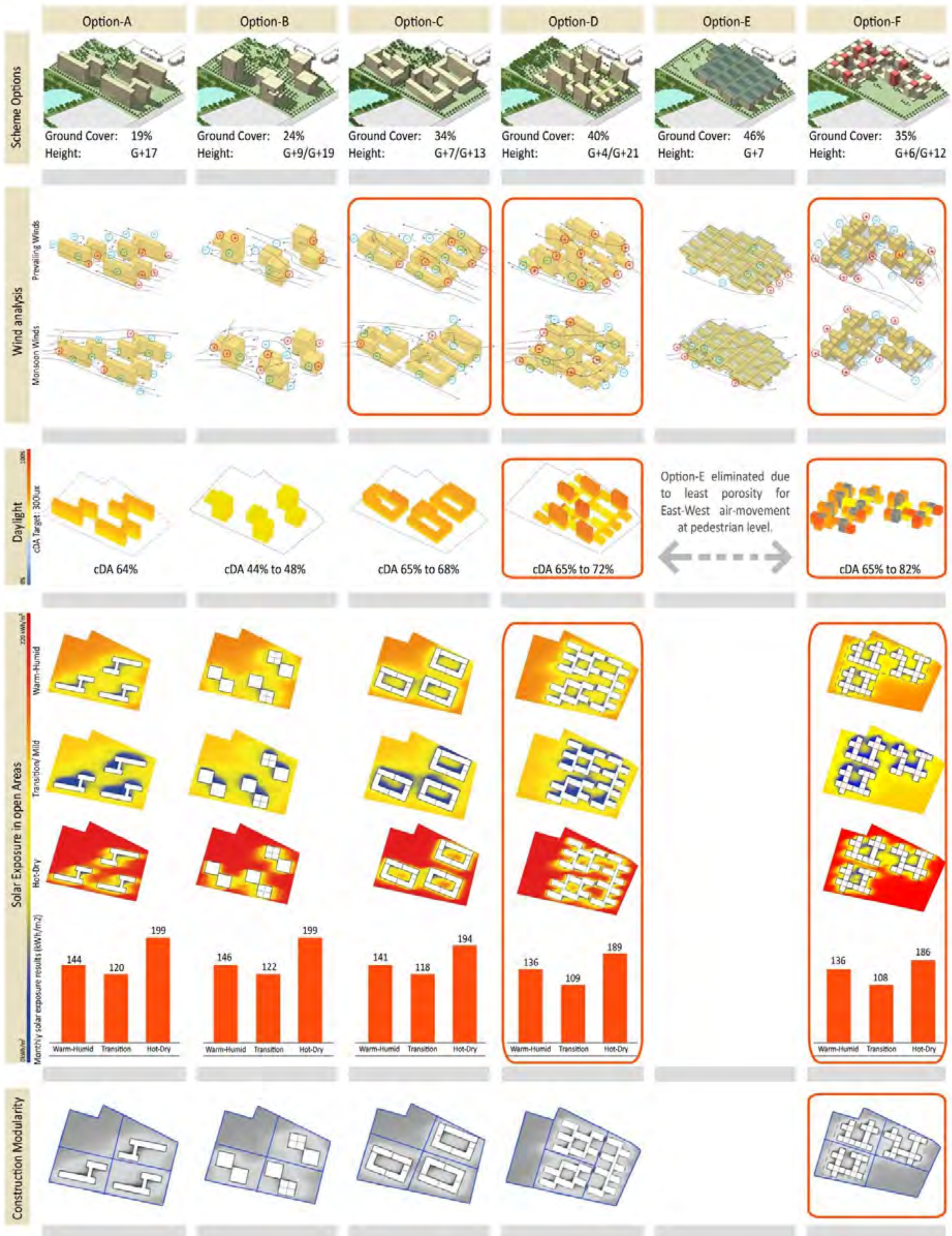


Figure 3. Methodology of Urban Design and Masterplanning for an IT campus in Hyderabad

from the construction requirement. Moreover, in addition to being a grand arrival plaza, the courtyard becomes a multi-functional gathering space at 10% of the conventional capital cost.

Built-Form

Modular efficiency involved an inside-out approach using a structural grid of 11.5Mx8.5M that could be a multiple of a workstation module as well as a car parking bay as the lowest

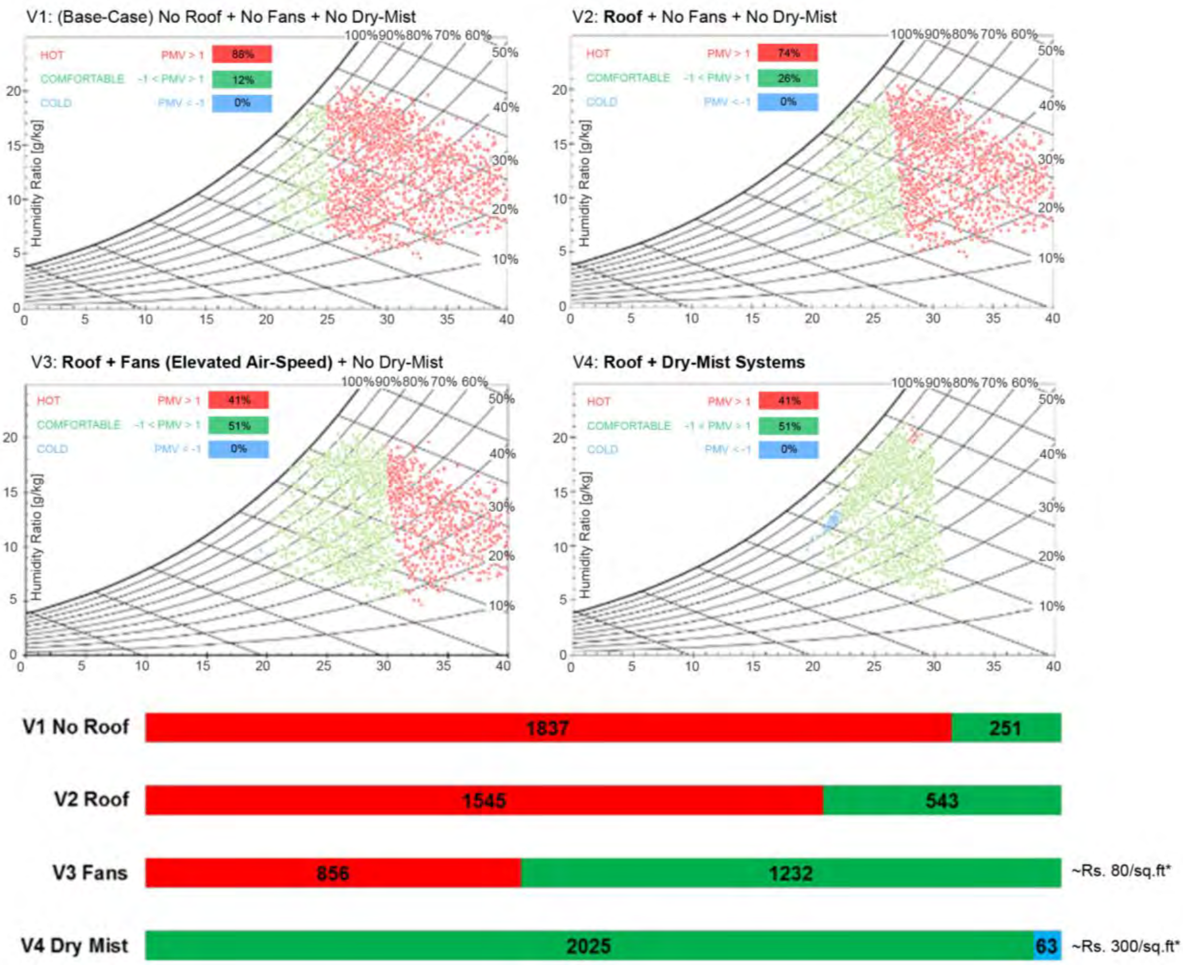


Figure 4. Comfort & Cost Evaluation for Outdoor spaces using the PMV model for adaptive comfort

unit. Workspace efficiencies of upto 45sqft./person were achieved with an overall 85sq.ft./person on built-up area. This further saved 15% of construction area as compared to conventional standards of 100sqft/person. High density work-spaces were expected to lead to high internal gains due to large no. of computers over a relatively lesser area.

Design of the built envelope was governed by balancing shade, glare, daylight distribution, solar heat gain reduction. Solar control for the external facade involved vertical fins and overhangs spaced according to the different orientations. Shading devices were designed with conscious attention to controlling glare without hampering the daylight distribution. External façade treatments are more often than not, eliminated during the course of a typical project as capital cost is generally given more thought over controlling operational costs. Moreover, maintainability of these features becomes more challenging over time due to high intensity of sun and air pollution levels in larger cities. These issues led to an integrated façade designed as an extension to the structure of the building with concrete slab projections and monolithic vertical fins, spaced relevant to the orientation.

The facades facing the courtyards were mostly protected by the roof coverings and could therefore be allowed to open up to the microclimate. Illuminance targets of 110lux were achieved by effective daylight distribution. The cumulative solar heat gains from the designed façades were calculated to assess the overall thermal efficiency of the envelope. Finally, the solar heat gain for the entire building was calculated and resulted in an overall thermal efficiency of 0.8W/sq.ft.

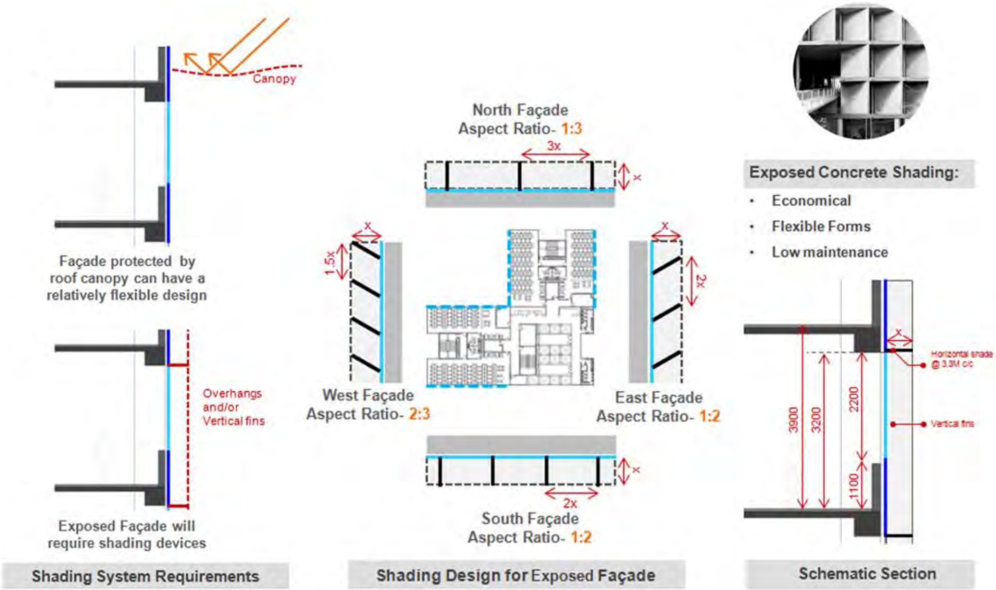
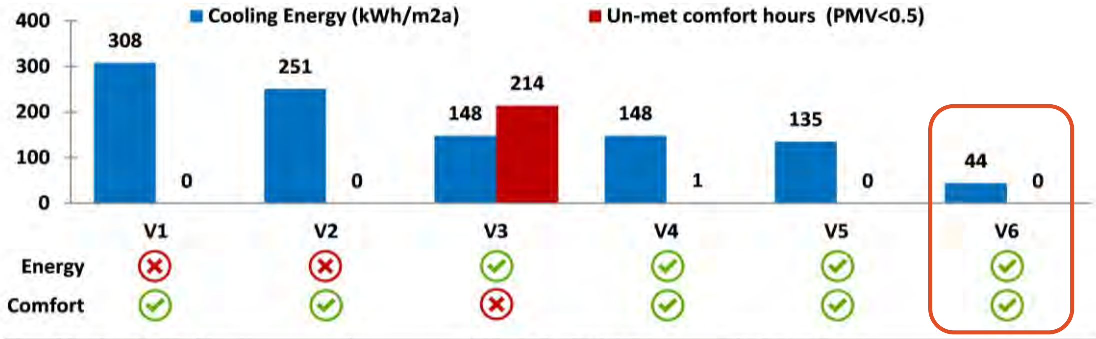


Figure-5. Integrated façade design for reducing solar gains through building envelope

Active Systems

Thermal comfort has proven to be crucial in achieving occupant satisfaction as well as workplace productivity. Setting comfort targets when the end user is not involved makes it essential to consider not only the adaptive factor but also expectations of comfort which may vary for different climate typologies. Working spaces demand consistent and controlled indoor environments for minimal distraction during focused tasks. Although minimal, the cooling loads as a result of microclimate creation and robust envelope design needed to be countered with active systems to achieve the desired comfort levels indoors.

Multiple cooling systems were analysed to achieve the most optimised solution specific to the project constraints. Innovative mechanical cooling systems including radiant cooling, under-floor systems as well as ceiling fans were explored in exclusive as well as combination scenarios. Feasibility analysis studies concluded with the selection of under-floor cooling system for controlled thermal comfort requirements in working spaces. The primary advantage was that the system offers flexibility in internal layouts enabling any future changes in market standards and user requirements. An iterative process was followed where finally the mechanical system allowed higher operative temperatures at elevated air speeds of 0.5-1m/s using ceiling fans was finally concluded (Figure-6). Under-floor cooling systems are generally useful due to the stratification of air in high-volume spaces. Adding air-movement at ceiling level is undesirable in such cases as it is expected to counter the process. However, floor heights limited to 3.9-4.5M are unable to benefit from stratification since temperature variations only upto the range of 0.5-1°C are achieved. Enhanced air-movement in such spaces hence, significantly adds to the physiological comfort. The overall advantages offer flexibility to the architecture as well as active systems.



Case	Cooling Method	Comfort Conditions	Interventions
V1	Under-floor air-conditioning (UFAD) system	Operative temp. ≤ 24°C, RH%≤ 60% Mechanical ventilation=20cfm	AC
V2	UFAD + Heat Recovery Wheel		HRW introduced
V3	Hybrid Tempered	PMV (with elevated air speed) < 0.5 mechanical ventilation=20cfm	Hybrid Tempered
V4	Hybrid Tempered		Internal gains from equipment reduced
V5	Hybrid Tempered	Operative temp. ≤ 25-26°C, RH%≤60% mechanical ventilation=13cfm Return air =30cfm	Mechanical ventilation system altered
V6	Hybrid Tempered	Operative temp. ≤ 28-29°C, RH%≤ 60% mechanical ventilation=13cfm Return air = 8.5cfm	

Figure-6. Sensitivity Analysis for Hybrid Systems integrating elevated air-speeds

A combination of natural ventilation and evaporative cooling may work for hot-dry conditions but highly humid environments make it very difficult to open to the outdoors without adding systems for dehumidification and enhanced air movement. Learning from the analytical studies where the effect of elevated air speeds on the microclimate was tested through installing ceiling fans in indoor spaces thus, creating hybrid systems to reduce mechanical cooling loads. Robust envelope design enabled common interactive functions within the built-spaces to be opened up for natural ventilation by using the same strategies of dry-mist systems in combination with fans. The basic understanding was that when occupants are not at work or are involved with interactive activities in a work environment, they tend to be more accepting and adaptive to their surroundings. Consequently, the microclimate could be further extended to comfortable transition spaces where another 35% of the total built-up area of the office building was made comfortable at half the cooling energy requirement of conventional practices. Combining passive principles of solar control and active systems for cooling proved to save another 50% of cooling energy in fully air-conditioned spaces (Table-3).

Table 3. Relative savings in construction area and cooling energy consumption

Area Distribution	*Use*	*Measures Considered*	*% age Area*	*Cooling energy savings*
Air Conditioned Spaces	Workstation areas, meeting rooms	**Under-floor cooling + Fans**	**56%**	**45%-67%**
Naturally Ventilated Spaces	Cores, Library, Food Court, Gym, Lobbies, discussion areas	**Natural Ventilation + Fans + Dry Mist Systems**	**35%**	**50%**
Shaded Outdoor Areas	Outdoor open cafeteria seating, recreation, library, arrival plaza	**Tensile Roof + Fans + Dry Mist Systems**	**9%**	**49%**

Conclusion

The comprehensive design process discussed above concluded at an overall construction cost falling well within £40/sq.ft. This factor was extremely crucial when addressing the budget constraints of projects in developing nations where saving in capital investment usually trumps operational costs. Overall, the office project in hot-humid conditions of Hyderabad can be seen as an exemplar for successful application of sustainable principles in hard-core cost-driven markets like India.

Pushing the potential of sustainable design requires expert inputs from multiple contributors like architects, climate engineers, structural consultants, mechanical, electrical, plumbing consultants, etc. Designing optimised systems and low energy consumption starts making commercial sense only when complemented by spatial efficiency. Energy consumption per capita becomes a crucial factor in analysing the efficiency of sustainable architecture in high-density markets. Similar applications of integrated design across the various tropical climate typologies have proven to be equally effective as can be seen in figure-7.

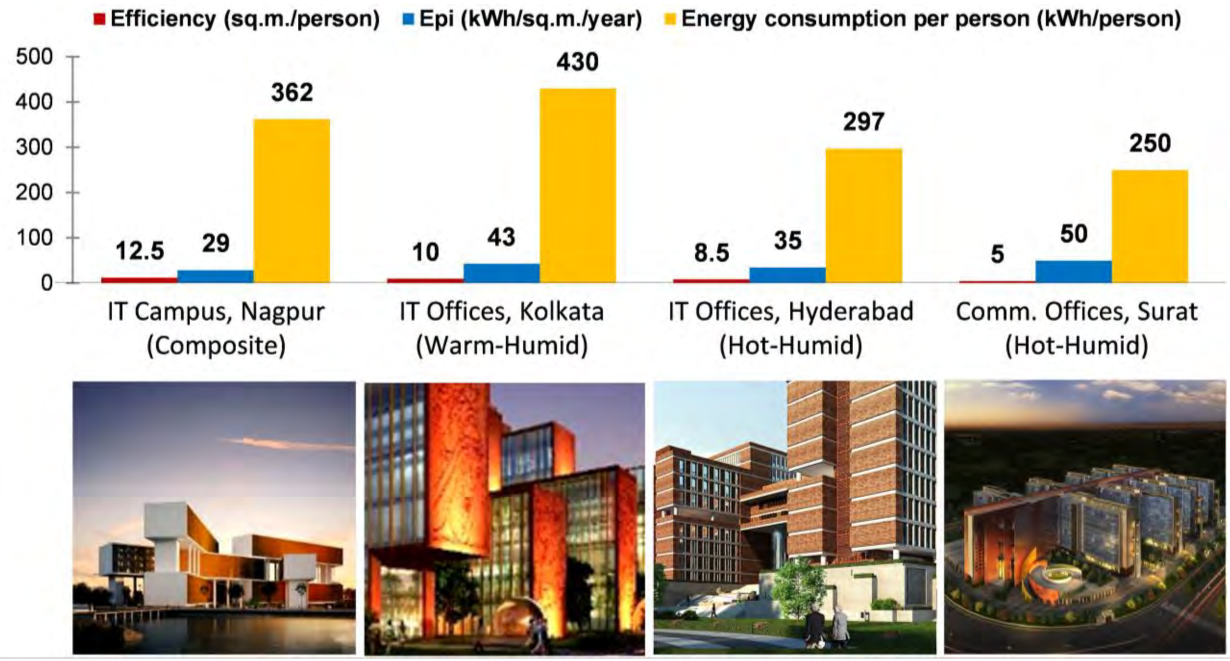


Figure-7. Applicability Of Integrated Design Approach Across Different Tropical Climate Typologies

Acknowledgments

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Design to Thrive

Passive Design Indices: Quantifying the Potential of Passive Design Strategies in a Climate

Jaydeep Bhadra[1], Prasad Vaidya[2] and Saket Sarraf[3]

[1] MTech, Building Energy Performance, Faculty of Technology, CEPT University, Ahmedabad, India;
[2] Professor – Area Chair, Building Energy Performance, Faculty of Technology, CEPT University, Ahmedabad, India;
[3] Dr. – Principal, ps Collective, Ahmedabad, India;

Abstract: The study focuses on developing indices to assess the potential for passive cooling strategies for a climate. Diverse microclimatic conditions are found within broader climatic regions at the scale of a few kilometres. Currently available climate analysis tools do not explore the interrelationships between different climatic parameters. Earlier work showed that it is possible to develop a weather-data-based classification to map the potential of some basic passive design strategies, such as building orientation. This study takes that approach forward to establish weather-data-based indices for advanced passive design strategies such as evaporative cooling, comfort ventilation, radiant cooling, earth cooling, and night ventilation. Weather data variables are identified for each strategy. Adaptive thermal comfort models represent the indoor comfort conditions. TMY weather data of 59 Indian cities and 2 international cities are analysed to develop the indices. Thermal Autonomy and Discomfort Degree Days are the metrics developed to measure the potential of the passive strategies. These will enable policy makers to develop climate zone maps that highlight the potential for specific low energy solutions in a region.

Keywords: Passive design, Indices, Climate, Potential, Low energy cooling

Introduction

Buildings consume more than 40% of world's primary energy and have a significant impact on Climate Change. Cooling accounts for 40%-60% of summer peak load in large metropolitan cities with hot climates like Delhi, and air conditioner (AC) sales in India are growing at 30% per year (CEM, 2014). Improved energy efficiency can be achieved using low-energy systems and passive design strategies. Identification of appropriate passive design strategies in early design stages thus becomes important to counter increasing energy use. And, understanding the potential for low energy and passive cooling solutions in a location enables the manufacturers and supply chains to market their products more effectively. However, there is a lack of regulation and support for widespread implementation of passive design strategies (Pawar, Mukherjee and Shankar, 2015). Earlier work shows that it is possible to develop a weather data based classification to map the potential of some basic passive design strategies, such as building orientation (Pawar, Mukherjee and Shankar, 2015). Development of such maps first requires developing a methodology for calculating indices that summarize the potential for passive strategies.

These passive design indices can be considered analogous to Cooling Degree Days (CDD) and Heating Degree Days (HDD). CDD is used to understand the thermal stress a climate places on a building, and provides an index to quantify the relative intensity of use of AC equipment across different climates; similarly, passive design indices can be used to understand the potential and relative intensity of use for low energy cooling methods to provide autonomy from air-conditioning. Literature suggests that most previous work on classifying a climate is based on a quantification of the stress, and passive strategies have been recommended based on the prevalence of certain climatic conditions. These recommendations do not use a quantified potential of any strategy in a climate i.e. it does not give any indication of the number of hours for which a strategy can be effective to achieve comfort. Furthermore, since within many regions, variations in microclimatic conditions can be found at a scale of a few kilometres, such recommendations may not be applicable similarly for specific locations within a climate zone. Therefore, there is a need for indices generated to identify the opportunity and potential of passive strategies in a climate for a location.

Levitt, Ubbelohde, Loisos, & Brown, (2013) proposed "Thermal Autonomy" as a metric and design process that links occupant comfort to climate, building fabric, and building operation. This metric is framed to avoid energy use and embrace the opportunities of the climate. It measures how much of the available ambient energy resources a building can harness, rather than how much energy heating and cooling systems will consume.

(Chiesa and Grosso, 2015) assessed the geo-climatic potential applicability of natural ventilative cooling for 50 reference cities in Mediterranean area based on a climate-dependent evaluation of the Natural ventilative Cooling (NVC) potential for different location using Residual Cooling Degree Hours (CDH_{res}) as a metric. CDH_{res} is defined as the AC-related virtual cooling needed for each location after the application of natural ventilative cooling.

This study develops the calculations to adapt Thermal Autonomy as a metric that can be used to assess the potential for 5 passive cooling strategies in a climate and remove the confounding variables that would otherwise make the calculations specific to a given building condition. Here, the objective is to calculate the maximum potential available for a strategy in a climate. Similarly, the study also adapts CDHres in to a metric called Discomfort Degree Hours, by replacing the Balance Point Temperature with the Adaptive Thermal Comfort control set-point. An analysis tool is developed to calculate these metrics for TMY weather data. The results from the tool that include data for 59 Indian cities and 2 international cities are presented.

Methodology

Identification of strategies and climate variables

Literature was reviewed to identify relevant climatic variables, heat sinks and physics for 5 passive cooling strategies (Evaporative Cooling, Comfort Ventilation, Night Ventilation, Ground Cooling and Radiant Cooling).

Stress in this study is defined as the distance (in degrees) between ambient condition and the expected comfort temperature for an hour. **Opportunity** in this study is defined as the availability of cooling potential in a heat sink (in degrees), to achieve desired comfort temperature for an hour.

Table 1 summarizes the strategies, heat sinks, climatic variables and the heat sink measure from the literature.

Table 1: Climatic Variables associated with strategies

Strategy	Sink	Climatic variables	Heat Sink Measure
Night Ventilation	Air	DBT	Diurnal Variation
Comfort Ventilation	Air	DBT & Wind Speed	$T_{in} – T_{out}$ (or, DBT), when DBT<T_{in}
Radiative Cooling	Sky	DBT, T_{dp}, & cloud cover	Difference between DBT and T_{sky}
Ground Cooling	Earth	T_{ground} & DBT	Difference between T_{ground} & DBT
Evaporative Cooling	Air	DBT & RH,	WBD (or DBT – WBT)

Source: Alvarez & Molina, (2003); Cook, (1989); Givoni, (1994).

Key Performance Indices

The potential of a strategy is determined based on its ability to provide required comfort temperature using the heat sink in the climate and is quantified using two indices, Thermal Autonomy (TA) and Discomfort Degree Hours (DDH). We remove the confounding variables such as building use characteristics, building physical characteristics, design approach, specific system design for a strategy and assumes the overall system efficiency at 100%; this enables us to calculate the maximum potential available for a strategy in a climate, and frees the building physics from keeping the calculations relevant to only a specific building or design condition. The results are to be applied to the climate and not to the performance of a specific building. If the objective is to measure the TA or the DDH for a given building or design, the same overall approach can be used after modifying the equations and applying appropriate system efficiencies.

We use the upper limit indoor operative temperature of an adaptive thermal comfort model; ASHRAE Std-55 or Indian Model for Adaptive (thermal) Comfort model (IMAC) as the base point to calculate thermal stress.

Thermal Autonomy (TA) is the ability to achieve comfort in a climate without the use of active systems. Thermal autonomy is achieved for an hour when stress is less than the opportunity as defined in Table 2. The summation of the number of hours for which TA is achieved out of 8760 hours gives the potential of a strategy in percentage.

TA = 1, if Stress < Opportunity for a given hour, otherwise *TA = 0*

DDH indicates the residual cooling required to achieve comfort after the application of a passive cooling strategy. It is calculated as the difference between stress and opportunity (in degrees), when thermal autonomy is not achieved for an hour. The summation of the DDH gives the total degree hours which indicates the residual cooling required.

DDH = Stress – Opportunity, when Stress is more than Opportunity

For example, in-case of evaporative cooling, for an hour the DBT is 37 °C, WBT is 35.44 °C and expected thermal comfort temperature is 30.57 °C, therefore the stress is (DBT -T_c) 6.43 °C and the opportunity is (DBT – WBT, i.e. WBD) 1.56 °C. Thus, Stress > Opportunity and hence TA is not achieved and DDH is (Stress – Opportunity) 4.86 °C.

Key steps to quantify Passive Cooling Design strategies

The key steps involved in the methodology are summarised in Figure 1 below.

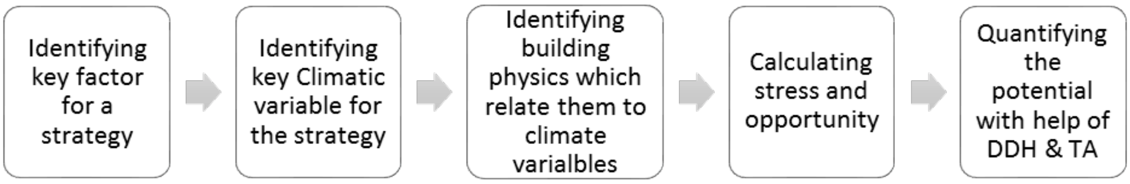

Figure 1: key steps involved in quantify potential for a strategy

Table 2: Stress and opportunity for strategies

Strategy	Key Climate Factors	Stress	Opportunity
Evaporative Cooling	Wet Bulb Depression	(DBT – T_c, when DBT> T_c)	DBT – WBT
Comfort Ventilation	Difference between T_{in} and T_{out} (DBT)	(T_{in} – T_c)	T_{in} – $\Delta\theta$[1]
Night Ventilation	Diurnal variation	(∑ (DBT- T_c), during daytime if DBT > T_c)	(∑ (DBT- T_c), during night when DBT < T_c)
Ground Cooling	Difference between T_{ground} and DBT	DBT – T_c	DBT – T_{ground}, when DBT>T_{ground}
Radiative Cooling	Difference between T_{sky} and DBT	T_{stag} – T_c	T_{stag} - DBT @ Night

Source: Cook, (1989); Givoni, (1994); Chiesa, G., & Grosso, M. (2015).

Tool

A simple graphic user interface tool is developed with user inputs (selection) for the city (climate data), the passive strategy, and the desired thermal comfort model. The tool has the capability to show comparative results for different strategies and cities. The calculations for TA and DDH are done for all 8760 hours in a year for 59 Indian cities. The output shows the results for TA and DDH summarized at monthly and annual levels. The tool can also be used to understand the variation in the potential of a strategy across different cities, and to understand the potential for different strategies for an individual location.

The software used is Ms Excel™, Ms Power BI™ and VBA™. The TMY weather file for each city is loaded into an Excel template, and the climate variables relevant to the physics of each strategy (shown in Table 2) are filtered. The calculations are processed in Excel for all the cities and the thermal comfort models, and the results are transferred into an Excel database. MS Power BI™ is used for the visualisation of these results data. The user can compare the potential of strategies with the flexibility to choose the cities, strategies and the thermal comfort models.

The tool allows architects and designers in their early design stage to evaluate the potential of different passive design strategies, and for policy makers to evaluate the potential of a strategy and how it varies across various climates of India.

[1] $\Delta\theta = 2.319\, v_{air} + 0.4816$ (°C), It is the air temperature decrease, perceived by a person as the effect of air movement (v_{air}). Source: (Chiesa and Grosso, 2015)

Results

Comparison of Potential for all 5 Strategies for 1 City (Annual Summary)

Figure 2: Annual comparison of 5 strategies for one city

In Figure 2, The annual summary of TA and DDH is displayed for all the strategies for the selected city and selected thermal comfort condition. For Bhagalpur, Bihar (Composite Climate as per NBC) evaporative cooling has the highest potential followed by ground cooling, radiant cooling and night ventilation. Comfort ventilation has the lowest potential over a year.

Comparison of Potential for all 5 Strategies for 1 City (Monthly Summary)

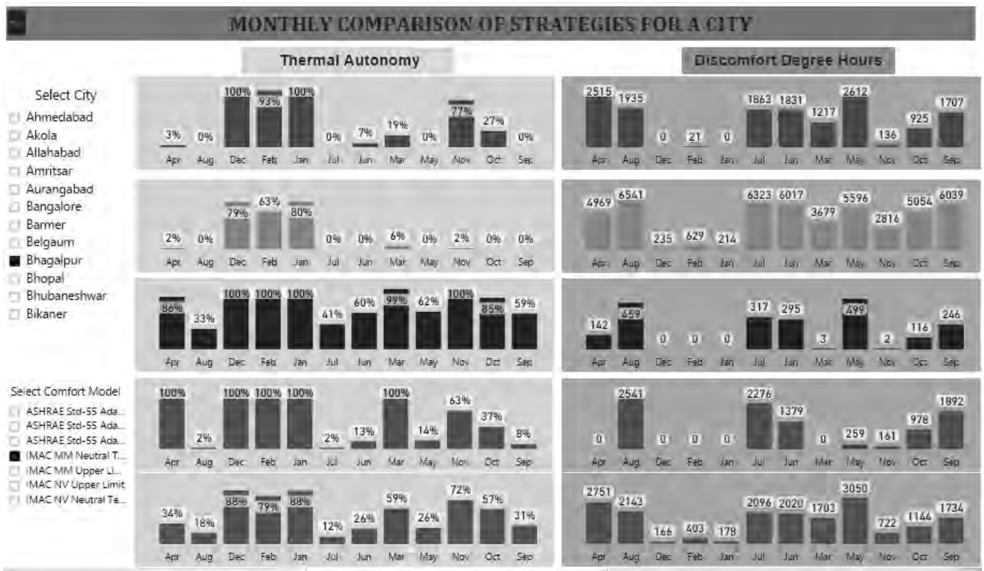

Figure 3: Monthly comparison of 5 strategies for one city

Figure 3 shows the monthly summary and provides a visualization of the variation over the year. The overlapping periods of applicability for the strategies can also be seen. For e.g. in the months of December, January and February all the strategies work well, however evaporative cooling, night cooling and ground cooling showing highest applicability. In this figure, though evaporative cooling has highest potential in Bhagalpur, it is less applicable for the months of May to September. Also in the month of June, evaporative cooling is the only strategy which will help to reduce DDH. Comfort ventilation only works for the months of December, January and February whereas night ventilation works only during November, December, January and February.

Comparison of Potential for all 5 Strategies between 2 Cities

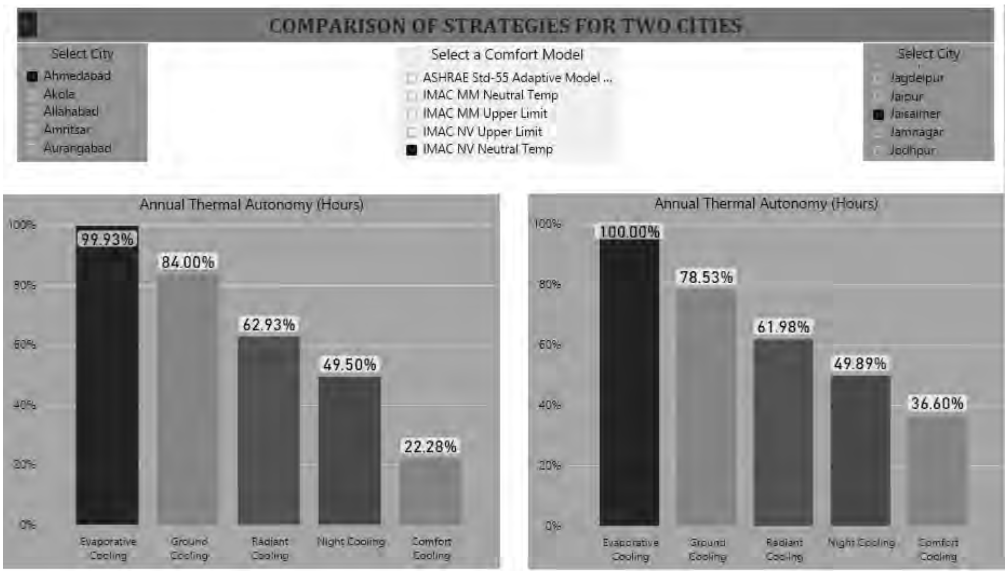

Figure 4: Comparison of TA of 5 strategies for two cities

In Figure 4, a thermal comfort condition is selected and two cities are selected for comparison. In this case, Ahmedabad and Jaisalmer show similar TA for all strategies except comfort ventilation and ground cooling. However, being in same climatic zone (hot and dry) as per National Building Code of India (NBC) (Bureau of Indian Standards (BIS), 2005), both cities shows different potential for comfort ventilation and ground cooling. Similar comparison is done for DDH also.

Comparison of Cities for a Strategy

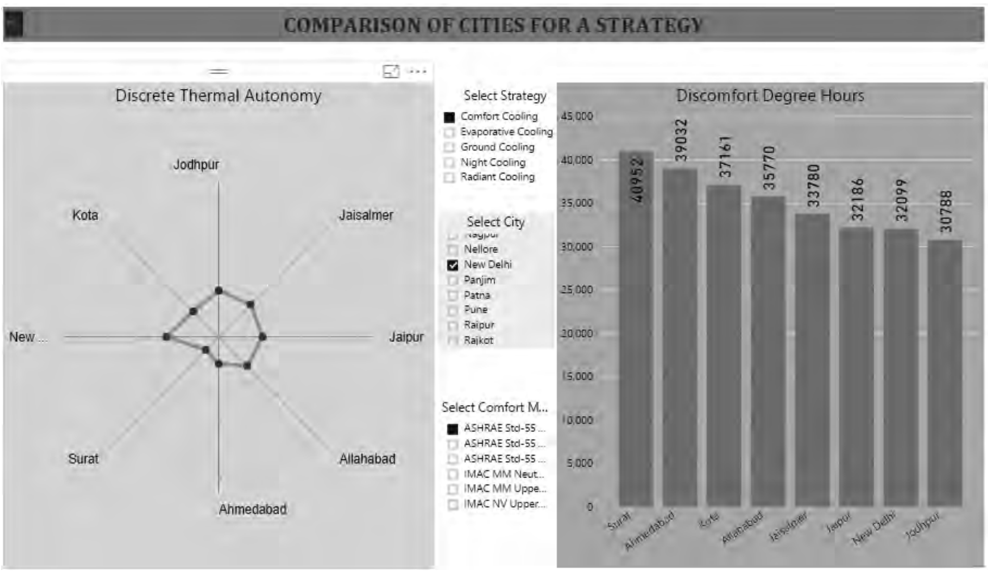

Figure 5: Comparison of Cities for a strategy

In Figure 5, a strategy and a thermal comfort condition are selected. Multiple cities can be selected for comparison. The spider graph on left shows the TA and bar graph on the right shows the DDH for selected cities. In this case, a significant variation in DDH can be seen for comfort ventilation across the selected cities. New Delhi (composite climate) shows higher DDH than Jodhpur (hot and dry climate). New Delhi has the highest TA (38%) for comfort ventilation followed by Jodhpur (33%).

Comparison of all cities (ranked) for a strategy

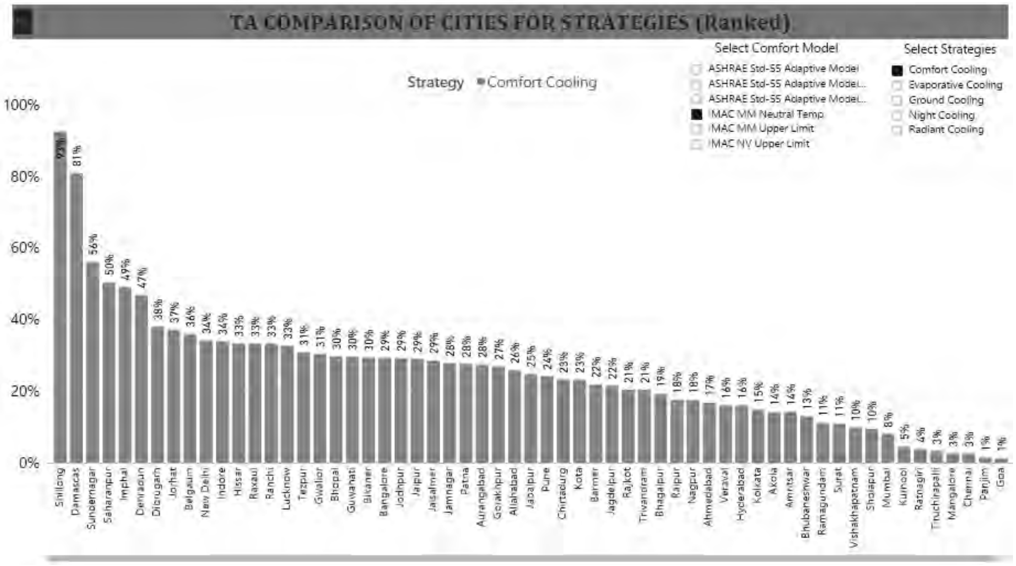

Figure 6: Comparison of 59 Indian Cities (Ranked) for a strategy

In Figure 6, the user selects a thermal comfort temperature and a strategy which is to be compared and all cities are ranked in decreasing order of TA. Cities that show a higher TA have higher potential for that strategy. A similar comparison may be done for DDH for all the cities.

Conclusions

This study uses Discomfort Degree Hours and Thermal Autonomy as two indices that can quantify the potential of a passive cooling strategy for a climate. This methodology and the indices developed allow comparison of cities for their potential for each strategy. It can compare the potential of strategies for cities at monthly and annual level. While some preliminary validation of the tool suggests that it shows expected trends, additional validation is needed before the methodology and its results can be used in design or policy-making. The results give an idea of the applicability of strategies in terms of Thermal Autonomy, and resultant intensity of use of AC in terms of Discomfort Degree Hours. The tool helps the user to identify the best strategy for a climate and the months when it is most applicable. This methodology can be used developing a TA and DDH map for each strategy for cities of India.

Acknowledgement

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Nomenclature

CDD	Cooling Degree Days	TMY	Typical Meteorological Year
HDD	Heating Degree Days	DBT	Dry Bulb Temperature (°C)
NVC	Natural Ventilative Cooling	T_{in}	Indoor Temperature (°C)
CDH	Cooling Degree Hours	T_{out}	Outdoor dry bulb temperature (°C)
T_{dp}	Dew point temperature (°C)	T_{sky}	Sky temperature (°C)
T_{ground}	Ground Temperature (°C)	RH	Relative Humidity (%)
WBD	Wet Bulb Depression (°C)	DDH	Discomfort Degree Hours
TA	Thermal Autonomy	T_c	Indoor Comfort Temperature
T_{stag}	Stagnation Temperature (°C)	NBC	National Building Code of India

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Design to Thrive

Procedural criteria for the design and construction of a low-cost solar greenhouse

Gian Luca Brunetti[1]

[1] Department of Architecture and Urban Studies (DAStU),
Polytechnic University of Milan, Milan, Italy. gianluca.brunetti@polimi.it.

Abstract: In this paper, the process followed for designing a low-cost botanical solar greenhouse in a river park in northern Italy is described with the aim of highlighting the strategies adopted to optimize it for robustness under peculiar site-specific constraints. The available design options were indeed substantially constrained by practical reasons deriving from the building site, the very tight budget, and the fact that the greenhouse had to be designed and finally self-built by the designers themselves: six student and two architects (the author included) in the short time (eighty hours) of a building workshop. Furthermore, the decision process had the requirement to be rational, due to the choice of basing each major decision step on a majority vote. The greenhouse has proved to be well-constructible. It will be used in the future for evaluating the correspondence between expected performances - as derived on the basis of thermal and lighting simulations - and recorded performances. The paper focuses on the peculiarities of the decision process that has been adopted, mainly derived from the necessity of "carving" the optimization process inside the reduced search space determined by the local constraints, and the choice of incorporating redundancy as desirable feature – a means for obtaining robustness at thermal and construction level. Some of the major constraints playing a role in the decision process, besides low cost, have been: the presence of a "C" shaped uninsulated concrete south-facing wall; the solar obstructions constituted by hills and deciduous trees; the necessity of avoiding construction delays due to the curing of mortars and concrete; the necessity of basing the control of solar shading devices and ventilation on seasonal, manual controls, so as to reduce the necessity of daily operations; and the necessity of adopting construction solutions suitable to forgive the low levels of precision of the builders.

Keywords: Greenhouses, passive solar gain, passive cooling, agriculture, self-construction

Introduction

Professional horticultural greenhouses are very seldom "bioclimatic". Their temperature is indeed usually governed by mechanical plants (Beytes, 2002; Taylor, 1999). But the main reason why bioclimatic design was not common for botanical greenhouses in the earlier past (the difficulty of succeeding in heating them passively - Hix, 1974) - is different from the present one: the present trend is mainly due to the higher construction costs of a solar greenhouse. Solar greenhouses indeed have to have a large winter solar aperture, and therefore a high height-to-depth ratio; which implies that they cover a small ground area per quantity of envelope used (Clegg and Watkins, 1978; McCullagh, 1978; Jones, McFarland, 1984). For that reason, solar greenhouses leaning to houses (Fisher and Yanda, 1976) in the last decades have had an overall greater success than independent solar greenhouses (Nearing and Nearing, 1977).

From a constructional viewpoint, wooden greenhouses are usually built with monolithic rafters and studs (Alward and Shapiro, 1980; Shapiro, 1984), which requires rather substantial quantities of wood for obtaining the load bearing resistance which is needed to resist the weight of the snow, but eases the construction process. (The required snow load in northern Italy is about 150 kg/sqm.)

In this paper, the process followed for designing and self-building a low-cost horticultural bioclimatic greenhouse in a river park in northern Italy is presented, and the outcomes of that process are discussed.

The design and construction activities in question have been carried out in eighty hours of a design workshop. The group of designer-builders was constituted by six master students (BS architects: Annalisa Banfi, Eva Cividini, Giovanni Di Fiore, Giacomo Lunghi, Federico Mira, Federico Monti) and two architects (Paolo Carlesso and Gian Luca Brunetti – who is writing this). In addition, academic colleagues of the author (prof. Remo Dorigati, with regards to the integration of the greenhouse into the site; prof. Carlotta Fontana and prof. Gianni Scudo, as co-ideators of the workshop) and the members of a local association hosting the project ("Contrada dei Calimali" - see acknowledgements and website) supported the design project with actions and ideas.

The construction site (coordinates: 45°39'59.70" N, 8°53'01.64" E) was owned by the association, which is active in the conservation of the landscape and in social activities in the zone of the Olona valley in the Lombardy region. The borders of the area including the design site are drawn in red in Figure 1 and the design site is signalled by an arrow.

Figure 1. The area owned by the association (in red) and the design area (see the white arrow).

The design area was square in shape, with edges of about 14 m; and the wall enclosing its north side seemed perfect for supporting a lean-to solar stand-alone solar greenhouse. The area was already being used as a vegetable garden and its horticultural use did not therefore have to change. The plot lay about 25 m near the Olona river, was about 5.5 m deep, and faced a chicken house and an orchard.

The precast concrete panels enclosing the plot (about 2 m high above ground and 2 wide) had originally been conceived for resisting horizontal forces and were therefore suitable for anchoring a light lean-to greenhouse and adding thermal mass to it.

The association agreed to have the greenhouse built on the vegetable garden in the context of a design and construction workshop, which was going to be structured in 10 session of 8 hours to be held twice a week (for a total of 80 hours). The wooden components needed for the construction activity were going to be donated by a sponsor. The other components were going to be bought.

The multiple purposes of the endeavour were that of minimizing the construction materials which were going to be used, making the greenhouses easy and quick to build and making its inner environmental conditions suitable for cultivation.

From constraints to decisions

Several constraints derived from the local conditions. The position of the greenhouse was already given, as well as the orientation of the back massive wall. So the length of the greenhouse and its shape in vertical transversal section were the main things to be defined by the design-builders. The back wall could clearly constitute and additional thermal mass for the greenhouse.

The original intention of the design-builders was to make the greenhouse small - a few meters thick and a few meters wide - and leave most of the available land in use as an open-air vegetable garden. But the wish expressed by the association was that of a longer, thicker, and higher greenhouse, stretched so as to "use" most of the available back wall, while keeping the greenhouse detached from the concrete walls enclosing the plot to the east and the west, so as to make possible entering the greenhouse from both sides. This last condition would have increased the thermal losses of the greenhouse during winter, but could decrease its thermal gains during summer, because of the shading action of the walls. And the increased size of the greenhouse in the making increased the importance of devising construction solutions which were efficient and easy to build.

Other design constraints derived from the micro-geographical context of the Olona river valley, which, in the given tract, is characterized by a stricture between hills, and runs with a north-south orientation. These conditions preserve the solar access into the valley during the central part of the day in all seasons, but disallow it during the summer mornings and afternoons; which is advantageous for reducing the likelihood of overheating during summers without reducing excessively the possibility of solar gains during winters.

Another important design constraint was constituted by the presence of a high deciduous tree to the south-south-west of the greenhouse site. The tree, besides shading the early-afternoon sun radiation during the summer, was likely to shade it also during spring and autumn.

Additional constraints were due to the very tight budget: about 1700 Euros were available in total. This encouraged the technical choice of using sawn wood components of small section (only 5 x 6 x 400 cm laths and 2.5 x 12 x 400 cm planks were used) and suggested to assemble them in truss configurations (for structural efficiency), discouraging the use of high-cost, high-impact glue-laminated wood. The economic constraints also encouraged the choice of alveolated polycarbonate glazing sheets in place of glass panels (the option of polyethylene foils was never an option, because the greenhouse had to be permanent), as well as the choice of anchoring them to the greenhouse with wooden "buttons" rather than wooden caps.

A further, considerable constraint was constituted by the lack of manual construction skills on part of the majority of the designer-builders. This encouraged the adoption of easy-to-execute construction solutions: for example, by opting for distributed connections by screwing rather than concentrated connections by bolting; and for connection configurations which didn't require a high dimensional precision - like lapped joints – rather than connections which required a medium level of precision - like butt joints.

The above constraints where combined with the requirement of making the greenhouse visually appealing, also considering that it had to host educational visits, and with a further condition self-administered by the design-builders: that of basing each design decision on a majority vote (which was of course possible because the team was small). That choice has had significant consequences on the design process, because it required that each designer-builder proposing a solution had to support it with reasonably sound reasons for convincing the colleagues. Which encouraged a rationalization of the decisions and made possible that many of them stemmed out from the design constraints.

It is also interesting to note that the described strategy for pursuing the design endeavour largely outlasted the design phase on paper (which took about two days) and prolonged itself well into the construction phase, in which the design and construction activities coexisted at the 1:1 scale.

Thermal design analyses

Due to the described constraints, the thermal analyses were mainly focused on determining the shape of the vertical transversal section of the greenhouse. The analyses took place in the periods between workshop days and were performed by the author in phases of increasing resolution. Before the decision was taken of filling almost completely the available plot space with the greenhouse, two batches of simulation-based explorations were performed. In both, the models – simulated by the means of the ESP-r simulation platform (see website) - were single-zone and had the glazing frames compacted in two symmetrical bulks at the sides (Figure 2, Figure 3).

These two former simulation batches were performed manually adopting shapes and materials which turned out to be not very corresponding to the solutions adopted afterwards. The greenhouse models in the first batch, in particular, were less thick and tall than those in the following batches, and featured operable openings also at the roof.

Moreover, in the first batch the solar obstructions constituted by the hills and the tree were not taken into account. They were taken into account only from the second batch onwards. Lastly, in the first batch, infiltration and ventilation rates were scheduled; whilst in the following batches mass-flow networks were used, built with the strategy of assigning the same pressure coefficient to all openings, so as to rule out from the calculations, as much as possible, the aerodynamic effects implied in the pressure coefficients, and include only the effect of thermal buoyancy.

The first simulation batch was overall devised so as to be very optimistic and let the designers perceive with clarity the “behavioural propensity” linked to the shape of each greenhouse section.

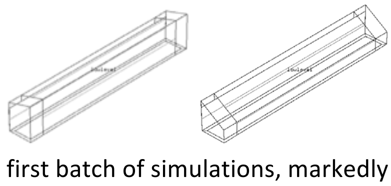

Figure 2. Some shapes tested in the first batch of simulations, markedly thinner than the one finally chosen.

The second simulation batch included the solar obstructions and was aimed to gain a feeling of the shading effects of the tree and of the thermal effects of the insulation of the back wall (at the outer face) and/or of the side walls.

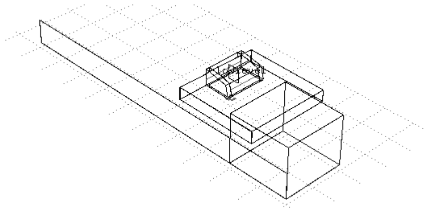

Figure 3. One of the models tested in the second batch of simulations, including the site solar obstructions and the ventilation nodal network. The greenhouse model is less wide and less thick the one finally built. The large boxed-shape obstruction represents a deciduous tree and was made partially transparent in winter. The site obstructions representing the hills are here still incompletely modelled.

The third simulation batch has been automated through the use of the Sim::OPT application (see website). It featured a larger volume (following the earlier stages of design decisions) and was aimed to evaluate comparatively and cumulatively the winter and summer thermal behaviour of the candidate greenhouse shapes. The performance ratings were carried out using indicators defined by the author on the basis of resultant temperatures.

The ventilation nodal network modelled for the task featured operable openings that were full-size on the front and back elevations, and were constituted by doors at the sides inserted in transparent walls. The ventilation openings were held closed in the simulations regarding winter (just the effect of the cracks was then in play) and 40% opened in the simulations regarding summer. Also, some of the evaporative effects of the vegetables were rudimentarily taken into account by including some wet surfaces in the models. The hypothesis of insulating the external surface of the concrete back wall with 15 cm of a plaster-like compound of straw, earth and lime was also taken into account.

In searching for a good shape for the greenhouse, three design parameters were taken into account: the height of the back top edge of the roof (which could assume 3 possible values), the height of the front top edge of the roof (which could assume 7 possible values), and the depth (y position) of the front top edge of the roof (which could assume 5 possible values).

The thermal indicators were obtained by defining a weighted indicator relative to heating and a weighted indicator relative to cooling for each winter month and for each summer month, and averaging the results. The months which were more likely to need both heat gain and heat dissipation (in the specific case, March and October) were taken into account with respect to both purposes, and as a result they had a double weight in the calculations; which is in line with the fact that for horticultural greenhouses the mid-season months are particularly important (usually, more than the seasonal extremes) for productivity.

More specifically, the indicator used for winter derived from the consideration that a high average temperatures combined with a small temperature swing (measured as the difference between monthly maxima and minima) was advantageous. Plants indeed do not like high daily swings (Shapiro, 1984). On that basis, the indicator was conceived as the sum of the average temperature and the difference between the highest monthly swing and the monthly swing of the case in question. That way, high average temperatures coupled with small temperature swings were given a higher score. The obtained score was then normalized (so as to be comprised between 1 and 0). In the same line, the indicator adopted for summer derived from the consideration that low average temperatures and a small temperature swing were advantageous. It was conceived as the difference of the average temperature and the difference between the highest monthly swing and the monthly swing of the case in question. That way, low average temperatures coupled with small temperature swings were given a higher score, then normalized.

The above indicators were devised so that no explicit weighting of objective functions was ever needed: nor in constructing the two indicators, nor in combining them.

The simulation results showed that heightening the greenhouse at the back increased its suitability for heating; and heightening it at the front increased its suitability for cooling. And with respect to the consequences of varying the depth (y position) of the top front edge, they showed that decreasing the greenhouse volume increased its suitability for heating, whilst increasing it increased its suitability for cooling (Figure 4).

Figure 4. Left: examples of shapes appropriate in winter. Right: examples of shapes appropriate in summer.

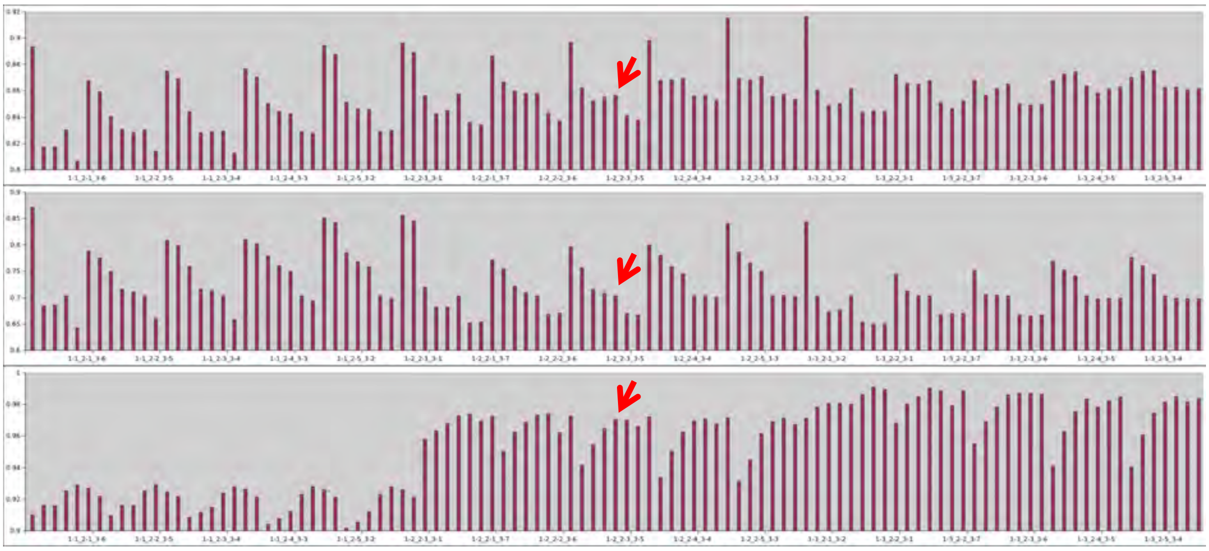

Figure 5. Rating of the simulated cases with respect to heating and cooling (top); to heating (middle); and to cooling (bottom). The higher the score, the more advantageous the option. The finally selected solution is signalled with a red arrow.

The greenhouse shapes which were selected for the project were, in the end, not the best performing; nor for winter, nor for summer, nor for the cumulated year; but it lay in the group of the “average” options (Figure 5). Indeed, constructional, usability and aesthetic consideration played an important role in the decisions.

A last batch of explorations was focused on the finally selected design option and aimed to determine the most advantageous seasonal arrangement of the openings. That batch also took into account the optional presence of shading nets on the roof. The response of those explorations was that in November, December, January and February the openings of the greenhouse should stay closed; that in March and October they should be kept a bit open (about 5%); that in April and September they should be kept wide open (about 60%); and that in the remaining summer months they should be kept wide open and additionally shaded at the roof by the means of a shading net (Fig. 6).

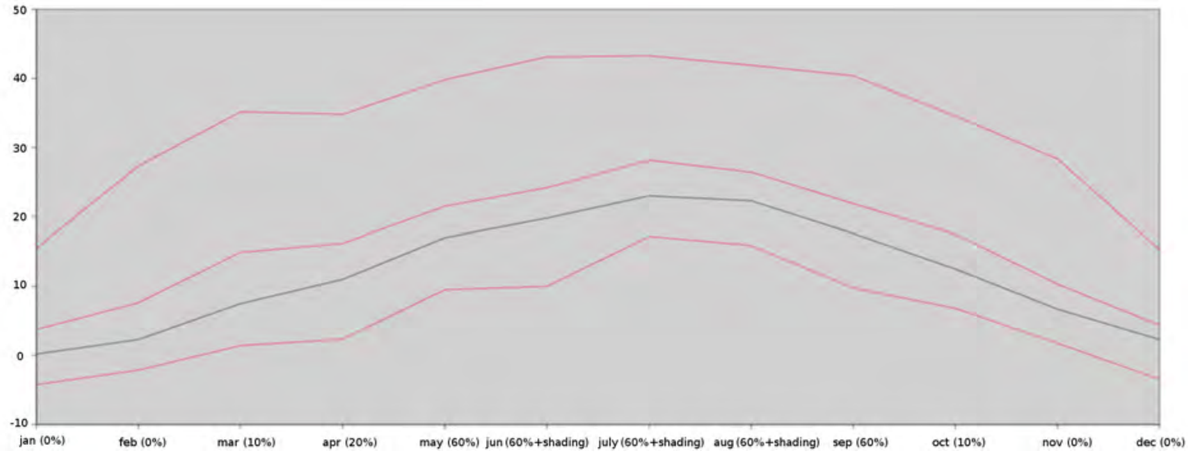

Figure 6. Predicted temperatures for the final design configuration in conditions of seasonal operation. In red: the resultant maximum, minimum and average monthly temperatures in the greenhouse (the percentage of ventilation openings and the use of shading devices is also signalled). In black: average ambient temperatures.

Construction decisions

The foundations of the greenhouse had to be constructed without waiting that any mortar-like materials set, so it was built dry, by digging a trench, half-filling it with gravel, then anchoring chestnut timbers to the ground with bent steel rods hammered diagonally into it. The greenhouse structure is characterized by the use of trussed asymmetrical portal frames spaced 2 m apart. All the portal frames have been built using almost only lapped joints. The structure has been conceived with the aim of providing redundancy, for robustness.


Figure 7. Progression of the construction phases and the outcome.

The openable frames have also been constructed with trussed configurations, for adding rigidity. In that case, butt joints were preferred over the more complex miter joints.
The horizontal bracing elements of the structure were hosted in a void layer inside the roof structure, so that both the diagonal elements, the top chords of the portals and the transversal rafters run uninterrupted (Figure 7).
The drainage of water was pursued by the means of internal flashings obtained by cutting a cheap fiberglass profiled sheet in strips (Figure 8).

Figure 8. Views of the operable openings.

Conclusions

The most distinctive construction solutions were that of using trussed structures not requiring high levels of precision and that of devising fully openable front and back facades for favouring ventilation. The results proved the constructional viability of both strategies.

With respect to the viability of the choices regarding the thermal behaviour and daylighting, the use of structured criteria for the exploration of the design options implying the indicators defined for the purpose allowed to support a rational decision process shared by the whole design-and-construction team.

Acknowledgements

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Low Energy, Low-Tech Building Design for the Extreme Cold of Antarctica

Gustavo Cantuária[1], Bruno Marques[2], João Pinelo Silva[3], Manuel Correia Guedes[4]

[1] UniCEUB, University Centre of Brasília, Brasil
[2] Construct, University of Oporto, Portugal
[3] Department of Architecture and Interior Design, University of Bahrain
[4] Higher Technical Institute, University of Lisbon, Portugal
Contact: manuel.guedes@tecnico.ulisboa.pt

ABSTRACT: The purpose of this research was to propose and build a sustainable, low-impact, optimized, modular lodge, to facilitate scientific studies in the Antarctic. Within this unique climate, this paper presents new environmental and sustainable approach for the extreme cold. The Polar Lodge was designed and built with a primary concern of proposing a zero carbon emission module. Other major concerns included that the proposal should be: modular; easy to transport and fast to assemble by a small team of non-experts (size and weight of parts was critical); resistant to wind; have minimum impact on the ecosystem; dry; warm; safe; physically and psychologically comfortable. The solution presented was inspired and adapted by the traditional Yurt. Scientific data was collected and analysed regarding the lodge´s performance in the extreme environmental conditions with the use of data loggers. The environmental comfort and thermal performance of the Antarctic yurt was tested for two consecutive days by the team of researchers in an isolated area on Collins Bay. Data was collected and the experience registered, substantiating environmental comfort on physiological, psychological grounds. Finally, this paper also intends to contribute to the scientific efforts of low energy building, within the concerns of climate change and sustainability.

Keywords: Low Tech, Energy Efficiency, Sustainable Architecture, Bioclimatic Dwelling, Cold Climates

Introduction

A vast body of knowledge has been produced on the problem of global warming over the last few decades. There are numerous publications on low-energy, sustainable, building design strategies for both European, U.S., and "developing world" contexts, resulting in an increasing awareness of the building sector that a change in paradigm is necessary. One can already find recent best-practice built examples of sustainable buildings, mostly in Northern Europe and the U.S. However, research into building designs for extreme cold climates such as the Antarctic is still at its infancy. Information is still necessary on a number of variables and, most of all, built examples of sustainable design, using low-energy strategies and eco-friendly materials, is required. This paper is based on the research and construction of such an example – a sustainable and self-sufficient building to lodge scientists during their field investigations in Antarctica. This research project, named Polar Lodge, is part of PROPOLAR, the Portuguese Polar program. It must be observed that there are huge ethical issues about any development in pristine areas such as Antarctica, often concerning waste disposal of the actual buildings themselves, and the local use of energy for heating. This constituted a motivating challenge, with positive impact in aspects of the long-term replicability of the solutions for other contexts, such as in cold climate regions in Europe.

This project is called Polar Lodge, and is a joint collaboration of the University of Lisbon (IST), the University of Cambridge, UniCEUB of Brasilia, and more recently the University of Bahrain. The project began in 2014, when a first two-week mission was carried out in the Antarctic Peninsula in order to assess both existing building typologies and occupants' expectations. A diverse variety of Antarctic Polar Stations were visited. Scientific data was collected and analysed regarding building performance in extreme environmental conditions, constructive characteristics of the existing pavilions, and energy and comfort performance of each building.

1. Field Work – Building of the Bioclimatic Antarctic Yurt

This paper investigates the building of a polar lodge in Antarctica. It was part of the initial objectives for the lodge to be modular, sustainable, reusable, easy to transport, and not energy consuming. The Mongolian Yurt, primitive yet efficient and environmentally friendly in its continental ambiance was the main case study due to the similarities of its characteristics with the proposed objectives for the polar lodge.

The initial intentions were to design and construct a sustainable prototype which allowed researchers moving in land to work away continuously from permanent bases in Antarctica with field work for up to two months (Antarctic summer time). For this a set of objectives were set:

- Be easily assembled by two people during an Antarctic summer day without any need of specialized training or skills for its assemblage;
- Reduced weight and dimensions to be carried by a zodiac (inflatable boat) or towed by ski motorbikes;
- Use of ecological and biodegradable materials;
- Ensure higher level of thermal comfort compared to tents;
- Ability to withstand wind gusts up to 120Km / h;
- Ensure acoustic and thermal comfort;
- Provide physical and psychological comfort.
- Allow the storage of modules on a permanent basis or in hangars during the Antarctic winter period;

The materials used in the construction of the Antarctic yurt were as follows: Base platform: plywood; Lattice structure: indented wood; Indoor finishing: two layers of natural wool with flameproof protection; Outdoor covering: waterproof biodegradable fabric;

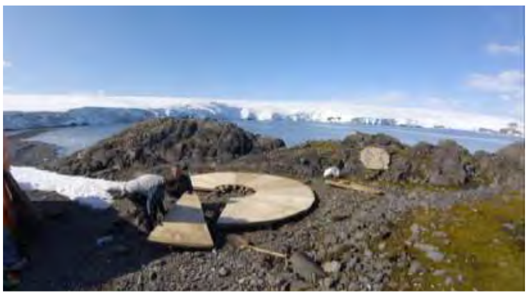
Figure 1: Site location in Collins bay, King George Island, Antarctica.

Figure 2: Collins bay, site for the Antarctic yurt

The assembly of the yurt took around 20 hours and was done in two days. There was a major concern in to adequate the terrain in the appropriate way, by levelling it and reinforcing the surroundings, therefore reinforcing the surroundings, therefore consuming more time than planned. Figures 3-15 illustrate how he 20 hours required for assembling the Yurt were divided:


Figures 3 and 4: Transferring the yurt materials from the zodiac boat to ashore (1 hour).

Figure 5. Levelling the terrain manually, where the yurt is to be implemented (4 hours).




Figures 6 and 7: Assembling the yurt´s wooden floor base (4 hours).


Figures 8 and 9: Installation of vertical trusses and application of its upper frame (4 hours).


Figures 10 and 11: Assembly of the multiple layers of thermal insulation (2 hours).


Figures 12 and13: Waterproof biodegradable membrane on the perimeter walls and roof (2hours).


Figures 14 and 15. Anchorage in 4 points, cable placement, fastening structure around the perimeter (3hours).


Figure 16 and 17: Assemblage completion of the Yurt.

2. Data Logger Measurements

After the yurt was assembled, it was prepared to be tested. Three data loggers were installed for registering measurements inside and outside of the yurt, on the 15th of January of 2016, and all three research team members slept in the yurt in isolation in front of Collins Glacier in Collins Bay. Given that the calibration, programming and activation of the 3 data loggers were done in advance still in Portugal, we must take into account the time zones – a four hours difference to the local time in Antarctica. The two data loggers called "inside 1" and "inside 2" are identified with the colours blue and green respectively in the graph, and were placed inside the yurt in opposite locations. The third data logger was denominated "outside" and labelled with the yellow colour on the chart. This data logger was placed on the outer face of the yurt, where to some extent it would benefit from the wind protection and thermal influence of the yurt indirectly.

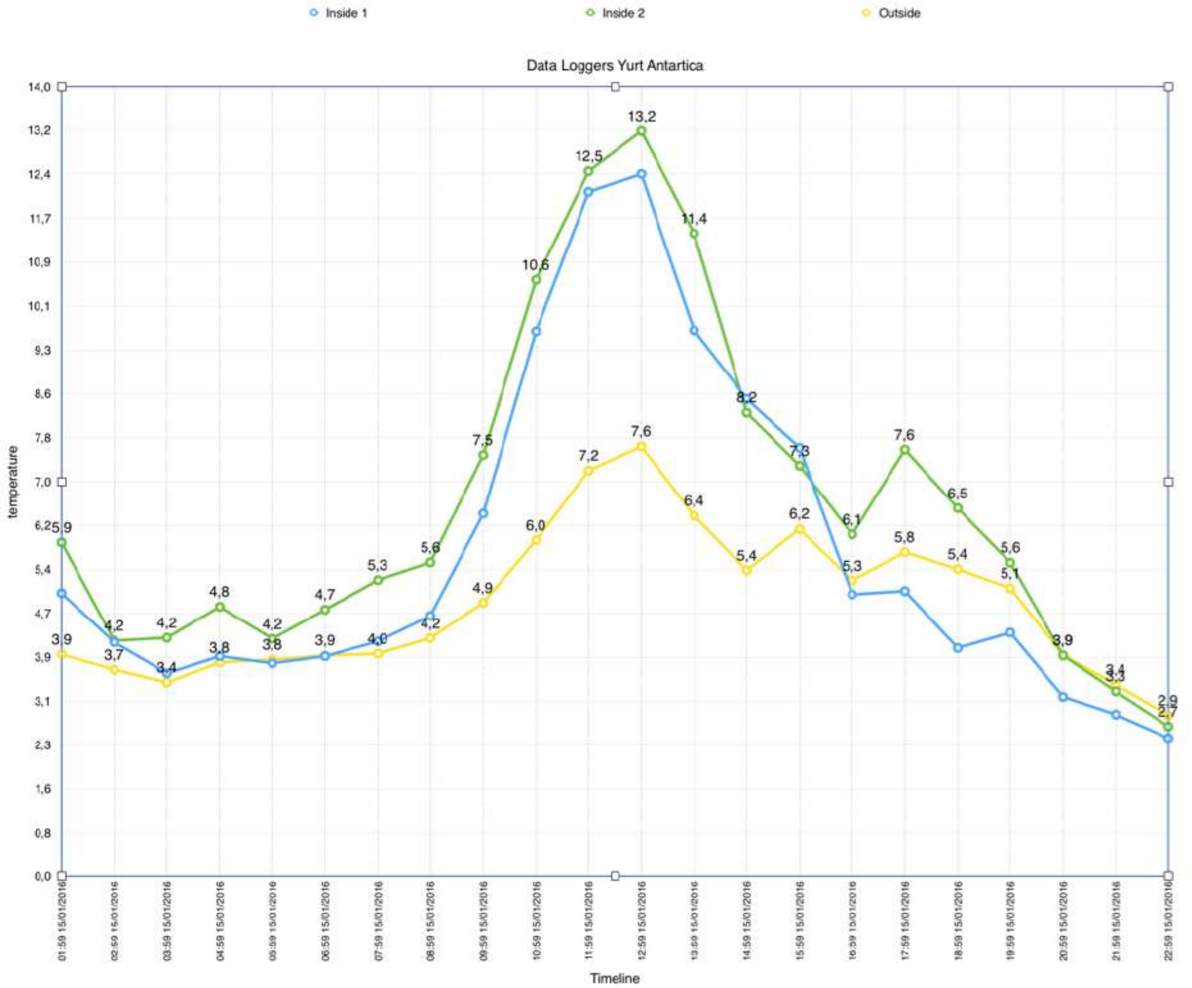


Figure 18: Graph showing the Data loggers' results in the yurt between the 15th and the 16th of January 2016.

The small difference in results between the two "inside" data loggers is due to their different locations inside the Yurt. "Inside 1" was positioned further away from the team members while the "inside 2" data logger was closer to the team members and the portable gas heater.

The research was done during January, the summer period in Antarctica and therefore with almost 24 hours sunshine. The first measurement was registered at 01:59 15/01/2016, corresponding to 21:59 local time, which is approximately the time at which the sun is at very low position and is blocked by the glacier wall near the site. Therefore from that time there is a lowering of the overall temperature in the absence of direct sunlight. The following four measurements (22:59, 23: 59, 0:59, and 01:59 hours local time) correspond to the completion of the assembly of the yurt's envelope, the mounting of the yurt camp beds in its interior, dinner preparation, and the firing a small portable gas heater air gas (figures 19 and 20). The yurt at this stage is starting to differentiate the internal and external temperatures and giving signs of high-energy performance with low technology.

Figures 19 and 20: images of the a portable low capacity gas heater

Seven of the following measurements (from 02:59 to 09:59 local time) correspond to the time when the team was at rest inside, and without leaving the yurt. Therefore at 10 am local time the average temperature difference between the internal and the external temperature was approximately 5.5 ° C, considering that the outside air temperature obtained was 7.6 degrees Celsius. However, it must be observed that the data logger denominated "outside" was located externally adjacent to the yurt and may have been influenced by the temperature increase inside the yurt, given the proximity of the data logger to the envelope. This observation is based on the fact that the average outside temperature was around 4.5 degrees, as registered at base camp. Furthermore, following the values of the Met station, the temperature difference between the inside and outside could have reached values greater than 9ºC, and close to double digits. In addition to help analyse the yurt's thermal efficiency, we used a FLIR thermal camera to obtain point readings of thermal performance of the interior and exterior. Images made it possible to prove the tightness of the envelope, the efficiency of the wool insulation, and identify thermal gaps as well as the range effectiveness of the heat source, as can be seen in Figures 21 to 23.

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Figures 21, 22 and 23. Thermal performance of the Yurt's interior.

Figure 24: The yurt's interior

Data Analysis

The data collected was analysed and studied, leading to important observations. The numerical information was confronted with the sensorial information registered by experimenting the environmental comfort of the Antarctic yurt by sleeping there. It is necessary to stress the value of not only physical comfort but also psychological (Brager, 1998; Canter, 1975). These psychological aspects will be further discussed in a different opportunity and paper. From the design and measurements collected, the following observations were reached:

- The compact, round, yurt shape enables a good thermal performance, and in addition performs very well against the wind when it is undifferentiated and flows in different directions throughout the day;
- The Yurt insulation made of two layers of natural wool with fireproof protection, still ensured significant insulation from the exterior;
- The inner insulation proved to be an efficient thermal gap barrier;
- Significant temperature differences were observed with the data loggers, of up to 6°C.
- The innate acoustic characteristics of the wool used, allows users of the yurt to perceive a level of acoustic comfort and greater sense of shelter when compared to the usual common tents; it allows for a total detachment from external wind noises, providing a great sense of security
- The natural incoming zenital daylight, allows for a comforting sense of place;
- The high floor-to ceiling height of the yurt provides valuable ergonomic space, allowing the user to stand up, move freely, and perform naturally any task;
- The construction of the yurt is completely biodegradable and environmentally friendly, fully adapted to the current requirements in Antarctica.

Conclusions

In recent years, research stations in Antarctica have depended on technology to build and maintain safe, and comfortable spatial environments. This implicates in higher costs and dependency on powered energy systems. High tech materials and systems also translate in future waste potentials and consequent pollution magnets, as unfortunately already can be seen in Antarctica. Pollution is a word, which should not echo in such a pristine place like the white continent. On the other hand, sustainability should be the order word when proposing any interference in Antarctica. In a lower building scale level, researchers are dependent on shelter to collect data in different fronts and in different places of the continent. At the moment this is mainly done by mounting tents and camps, which are neither safe nor comfortable. With this scenario in mind the Polar Lodge project proposed the first flexible, modular, demountable, portable, and sustainable shelter in Antarctica. Consequently the Polar Lodge was successfully designed and built to be sustainable, self-sufficient, easy to transport and assemble. More importantly it is able to withstand freezing summer temperatures providing comfortable (both physically and psychologically), and safe spaces with minimum impact on the surroundings, and independent of fossil fuels or electricity, maximizing energy efficiency through the choice of materials, form and design. The Antarctic yurt has been used by different scientists, setting an example of low environmental impact, ecological, and sustainable design.

Future Studies

This paper discusses the results of fieldwork in Antarctica in light of designing sustainable and resilient buildings in harmony with an extreme climatic context and limited local resources. Studies may progress in looking into low technology but high energy efficiency design as means to attain a neo vernacular architecture, one which benefits from modern materials and structures but are rooted on passive building concepts. Future building design strategies also include the use of sun and wind power to be a building component for the Antarctic, aiming to be self-sufficient in terms of energy consumption, through the use of renewable energy systems, as well as an optimized environmental performance. Finally, the intention of this paper is to contribute to the scientific efforts that are being invested in the Antarctic within the concerns of climate change.

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Design to Thrive

Exploratory analysis of the user behaviour influence on daylight performance of an office room oriented to East in a tropical climate

Juliana Carvalho[1], Viviane Hazboun[2], Allyson Santos[3], Aldomar Pedrini[4]

[1] Environmental comfort and energy savings, Faculty of Architecture, Universidade Federal do Rio Grande do Norte, Natal, Brazil, juliportela@gmail.com;
[2] Environmental comfort and energy savings, Faculty of Architecture, Universidade Federal do Rio Grande do Norte, Natal, Brazil, vivianehazboun@gmail.com;
[3] Environmental comfort and energy savings, Faculty of Architecture, Universidade Federal do Rio Grande do Norte, Natal, Brazil, css.allyson@gmail.com;
[4] Environmental comfort and energy savings, Faculty of Architecture, Universidade Federal do Rio Grande do Norte, Natal, Brazil, apedrini@gmail.com.

Abstract: This work explores three patterns of occupants' control of window blinds and the potential influence on daylight performance of an office room oriented to the East. In Natal city (5° S), Northeast coast area of Brazil, windows oriented to East are frequently obstructed by curtains, despite the daylighting and the exterior view. The daylight discomfort leads the occupant to close the blinds. The consequences are obstructed outside view, poor daylight quality and dependency on artificial lighting. This paper assesses the impact on available daylight using parametric analysis based on daylighting dynamic computer simulations run in Grasshopper and Daysim software, and the parameters assessed are window-to-wall ratio (40% and 80% WWR), sky view factor (small and large SVF) and occupant behavior (active, intermediate and passive users). The performance criteria combines Useful Daylight Illuminance (UDI500-5000lux) and illuminance uniformity distribution. Results confirm the role of user behavior on the daylighting performance. The combination of external shading devices, high Sky View Factor (SVF) and high window size can make daylighting user proof for 1/3 of the time, and can double the daylighting performance if combined with an active user.

Keywords: Daylighting, occupant behavior, fenestration systems.

Introduction

Occupant behavior plays a significant role on daylight performance of office buildings (Foster ,Oreszczyn, 2001; Mahdavi *et al.*, 2008; Fabi *et al.*, 2011; Yan *et al.*, 2015; D'oca *et al.*, 2016) which depends on presence, actions and occupancy profile (Rijal *et al.*, 2007, p. 824 e 825). The performance optimization emerges as a double challenge, which depends on technical and human requirements (Hong *et al.*, 2015; D'oca *et al.*, 2016).

Over the last few decades, many studies have focused on bridging the gap between the energy performance of predicted and real buildings, increasing the importance about the user behavior (Fabi *et al.*, 2011; Hong *et al.*, 2015). The complicating factor is the uncertainty of actual interaction and diversity of occupant profiles (Reinhart ,Voss, 2003), which includes passive and active users. Each occupant behavior pattern requires different technical solution for the building systems, which may affect the interactions between them (Yan *et al.*, 2015).

The behavioural models in building performance simulation often focus on the manual opening windows and lighting control, including the operation of shading devices. Hong *et al.* (2015) proposed a DNAs framework to formalize the modelling of energy-related occupant behavior, using four many components: *drivers*, *needs*, *actions* and *systems.* Reinhart *and Voss* (2003) present an approach that mimics manual lighting and blind control in private offices called *Lightswitch*. The algorithm is based on direct sunlight above 50W/m², witch induces the control when the occupant arrives or leaves the room.

External devices, including blinds, louvers and overhangs, are commonly indicated to tropical climates, due the excessive solar radiation (direct and diffuse) and overheating. When properly designed, can prevent glare and direct radiation (Stack,Goulding ,Lewis, 2000; Inkarojrit, 2005; Tzempelikos, 2005; Kirimtat *et al.*, 2016), decreasing the use of internal blinds, which are inefficient for external view, lighting and thermal performance.

Previous studies on daylighting evaluation for tropical climates (Carvalho, 2014; Moreno, 2015; Dias, 2016) show the importance of using shading devices to optimize the performance. The daylight performance can be expressed by the correlation between WWR and SVF. Models with small WWR (e.g. 20%) need a high SVF to have a daylight zone for the half of the room. Models with intermediate WWR (eg. 40-60%) must be totally shaded, with a small or intermediate SVF to achieve practically the entire room depth. Models with high WWR (e.g. 80%-90%) must be completely shaded, with a small SVF to reach the entire room depth.

Objective

This paper aims to assess the impact of occupants' control behavior on fenestration systems in daylight performance of office buildings in a tropical climate.

Methodology

The procedures consist in defining representative models, with simulation and parametric analysis of daylight performance (Figure 1). The models are based on local office buildings assessment, with a zone 5.00m large and 7.00m depth and a single window orientated to the East. The models varies in terms of without exterior shading (with horizontal overhang 1.5m depth and fixed external blinds), two sizes of windows (40 and 80% WWR), two sky visible factor (low and high SVF[1], **Error! Reference source not found.** and **Error! Reference source not found.**), and three user behaviors. The reflectivity properties of the internal surfaces (Table 1) were determined based on the Brazilian code (Abnt, 2013).

The three patterns of occupant interaction with window blinds are based on visual discomfort, and consist of:

- Passive user: the occupant ignores the daylighting turning the artificial light on and closing the blind when the room is uncomfortable. The occupant does not open the blinds anymore during the same day;
- Intermediate user: the occupant ignores the daylighting turning the artificial light on and closing the blind when the room is uncomfortable. The occupant does not open the blinds during that specific time period, and take the control action just when returns to the room.

[1] "portion of the sky visible at a given point (observer) and it depends the size of the source" (Leder, 2007)

- Active user: the occupant closes the blinds when the room is uncomfortable and opens the blinds when the available daylight does not cause discomfort. The control is similar to an automatic system.

The daylight criteria evalutation is:

- minimum illuminance of 500lux (Abnt, 2013);
- maximum illuminance of 5.000 lux;
- uniformity, with illuminance levels ratio less than 1/10 (maximum and minimum illuminance level ratio must be less than 0.1) (Abnt, 1992).

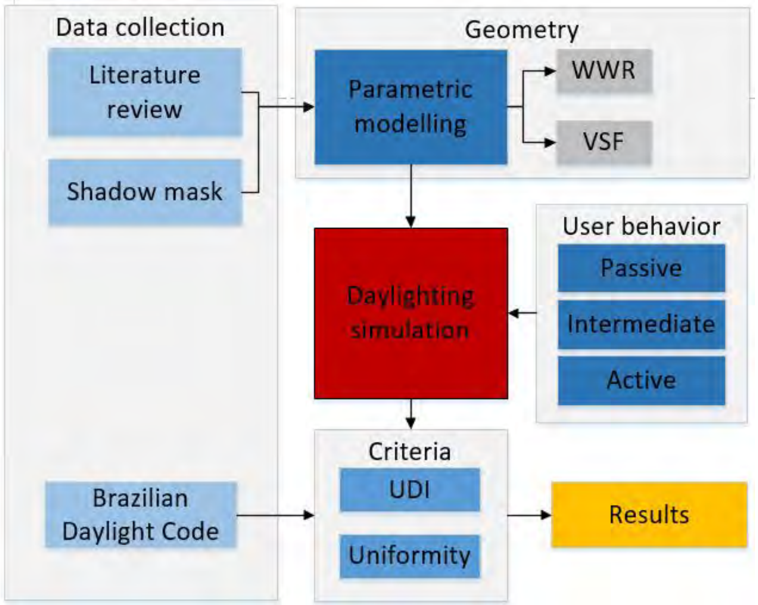

Figure 1. Procedures.

Table 1. Reflectivity of materials.

Elements	Light reflectance
ceiling	0.6 - 0.9
wall	0.3 – 0.8
work plane	0.2 – 0.6
floor	0.1 – 0.5

Source. (Abnt, 2013).

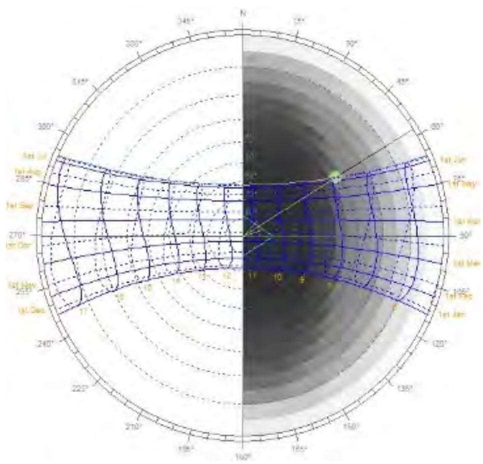

Figure 2. Low SVF.

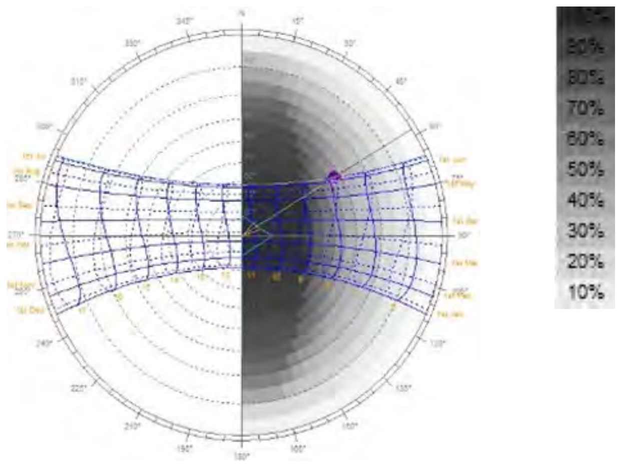

Figure 3. High SVF.

The combinations between window-to-wall ratio (WWR) and sky view factor were defined based on shadow masks simulated in Ecotect software (Marsh, 2011).

The geometry was parametrically modelled in Grasshopper/Rhinoceros (Rutten, 2015) and the models were simulated in Daysim (Reinhart, 2010). The input data of the simulation were geometric model, occupancy file, user behavior, sensors file, climate file and materials properties of the room surfaces.

The sensors distribution was designed according to Brazilian Code Standard (Abnt, 2005), which determines the identification and distance of the points (Figure 4 and Figure 5).

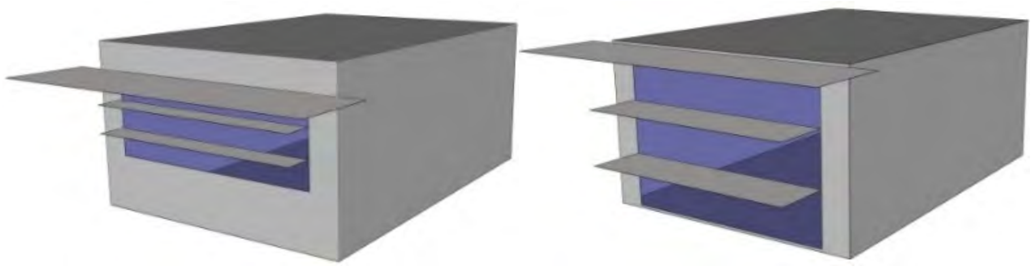

Figure 4. Exterior shading for 40% and 80% WWR.

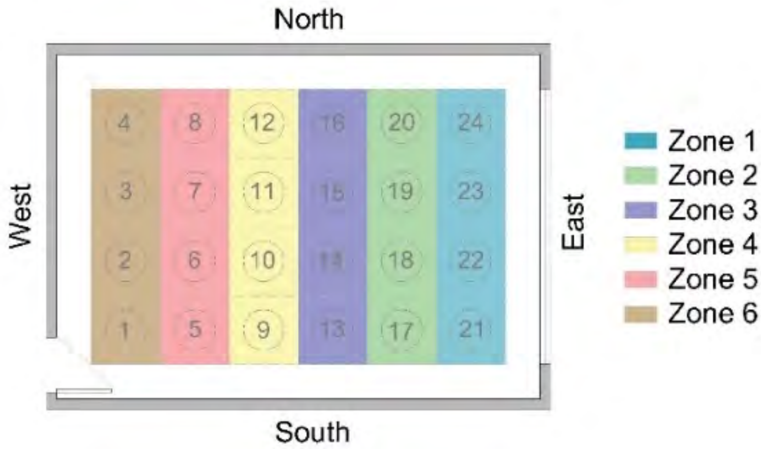

Figure 5. Sensors and zones distribution.

The performance parameter is an adapted Useful Daylight Illuminance (UDI) between 500-5000lux, with comfortable daylighting uniformity, calculated in electronic spreadsheets, and graphically organized in terms of zone depth for each WWR.

Results

The results show the almost complete lack of daylighting use for passive users, and the maximum daylight performance for active users of the room with high SVF, 40% (Figure 6) and 80% WWR (Figure 7), which can reach up to 55% and 85%, respectively, at the first and second zone depths.

Passive users blind the window since the early hours due to the penetration of direct solar radiation, causing high levels of illuminance and unsatisfactory uniformity for models without exterior shading (Figure 8 and Figure 9). Models with exterior shading and low WWR varies from lack of illuminance to unsatisfactory uniformity.

Results of intermediate user in rooms without shading indicate the potential use of daylighting at afternoon when the blinds are opened after lunch, with approximately 35% of occurrence for both window sizes, reaching the second zone depth for 40%WWR and third zone depth for 80%WWWR.

The difference between intermediate and active user for room without exterior shading is attributed to the available daylight at later morning hours, which can improve to approximately 10% of daily use.

In models with external shading, increasing the SVF, the performance increases more noticeable in 40%WWR models and 80%WWR models with active user. Increasing windows size and SVF also increases the zone depth performance.

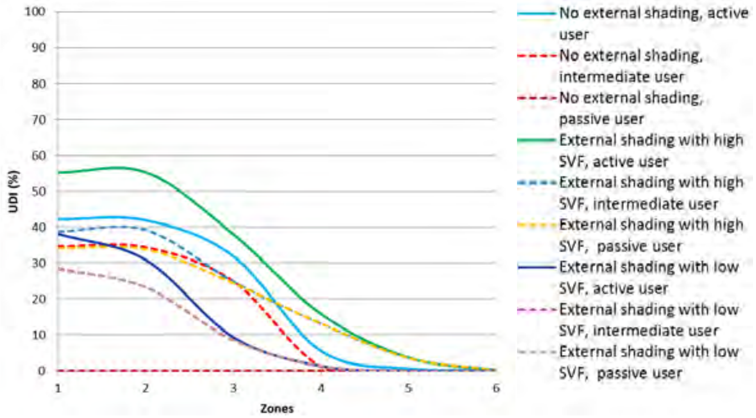

Figure 6. UDI for 40%WWR.

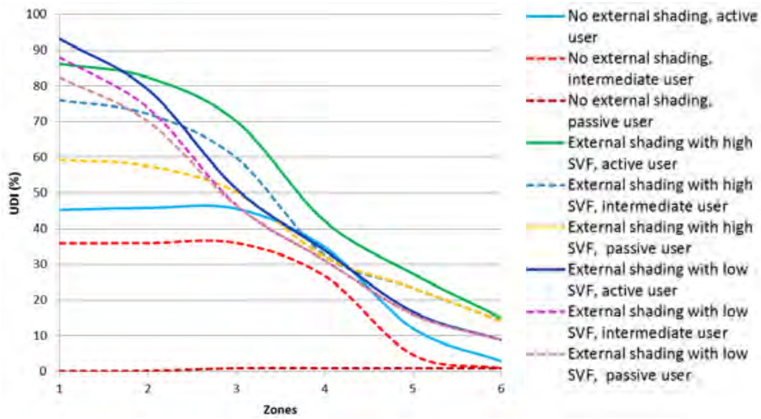

Figure 7. UDI for 80% WWR.

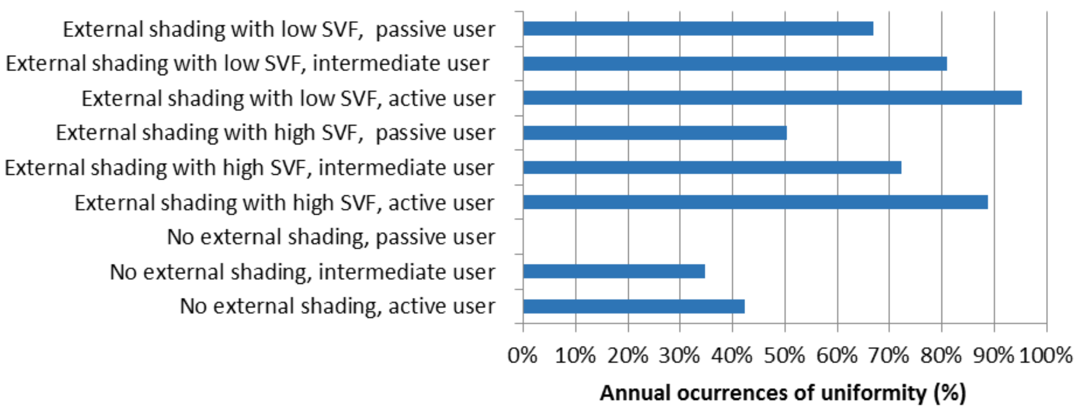

Figure 8. Occurrences of uniformity for 40% WWR.

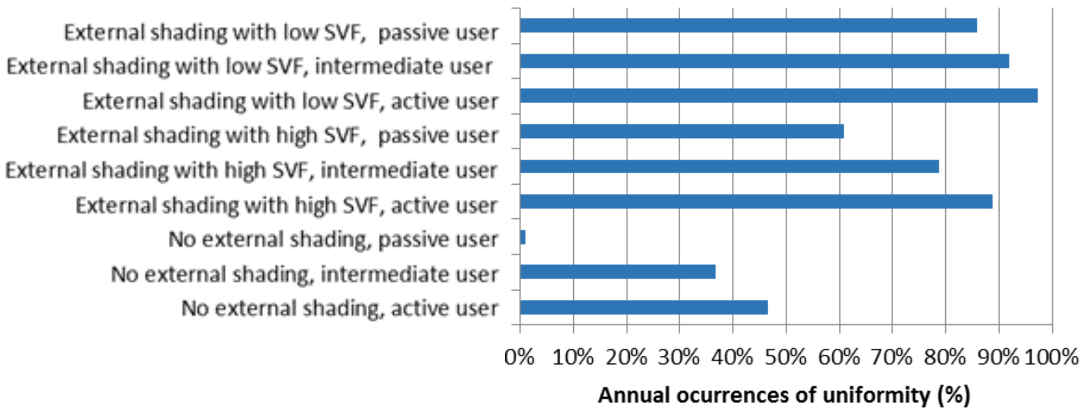

Figure 9. Occurrences of uniformity for 80% WWR.

The best-performing model at zone 1 has external shading with low VSF and active control, presenting an occurrence of uniformity of 95% for WWR 40% and 97% for WWR 80%. In this case, the impact of user behavior is more significant with a small WWR. Results show that the difference of occurrences of active and passive users is 30% with a WWR 40% (Figure 8) and 10% for WW 80% (Figure 9).

For the scenarios with high VSF, the influence of user behavior is already more noticeable. For WWR 40%, there is an occurrence of 88% for active users and 50% for passive users (Figure 8). For WWR 80%, active users promoted 88% of uniformity and passive users, 60% (Figure 9).

The procedures demonstrated limitations of the Grasshopper software:

- The component “read annual result” do not generate graphic results for the UDI determined by the design illuminance for dynamic shading.
- The component “EPWindow shade” do not generate user behavior interactions according to different comfort variables.

Conclusion

As expected, the use of daylight is highly influenced by the user behavior depending on the geographic localization. The unsatisfactory performance in the early hours demands adjustments that block the daylighting, leaving the user without further discomfort stimulus to make new adjustments to use daylight. The intermediate user could beneficiate from the lunch break to get a stimulus to open the blinds. The active user, more hypothetical than real, could represent someone very attentive and connected with the exterior. Nonetheless, these results also demonstrated the importance of a blind automatic control, which could result in daylight use for most of the time at the three zones close to the window.

The architectural characteristics of window size, external shading and SVF play a major influence on daylighting performance. In combination with an active user or automatic blind control, they can make daylighting useful for 2/3 of the time for the first half of the room.

The user behavior modelling requires more refinement in future developments, including glare perception and intermediate shading adjustments.

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In-situ measurement analysis of indoor thermal comfort of a natural ventilated residence in Taiwan

Lily Chang[1], Ying-Lien Chiu[1,2], Ruey-Lung Hwang[3] and Kuo-Tsang Huang[4]

[1] Treasure Dragon Corp., Taichung, Taiwan, eva@lpd.com.tw;
[2] Department of Architecture, Feng-Chia University., Taichung, Taiwan, eva@lpd.com.tw;
[3] Department of Industrial Technology Education, National Kaohsiung Normal University, Kaohsiung, Taiwan, rueylung@nknu.edu.tw;
[4] Department of Bioenvironmental System Engineering, National Taiwan University, Taipei, Taiwan, huangkt@ntu.edu.tw;

Abstract: In the past, the absence of in-depth investigation on the energy saving design of housing construction by designers and developers has resulted in unnecessary excessive energy consumption. Passive design strategies, which are considered easier to be realized in housing industry, are undoubtedly the most direct and efficient method to achieve energy saving in the vigorously promoted green building era in Taiwan. Natural ventilation is an efficient passive design means that integrates climate design to achieve building energy saving and create healthy environments for human habitat. To investigate the effect of utilizing natural ventilation on improving the residential indoor thermal environment in Taiwan, in-situ measurement of an apartment building, whose design followed the current Taiwanese green building guidelines, was conducted during seasons suitable for natural ventilation. Long-term indoor and outdoor ambient temperature and relative humidity were monitored. The indoor thermal environment was analysed against the measured data. The analytic results confirm the effectiveness of several utilized passive design strategies that followed the green building design guidelines to improve the indoor thermal comfort.

Keywords: thermal comfort, naturally ventilated residence, green building

Introduction

The time people spend indoors accounts for about 80% of their life time. With ever better living conditions, people have paid increasing attention to indoor thermal comfort. As far as indoor thermal comfort is concerned, the problem of indoor overheat can be solved with an air conditioner. Correspondingly, a survey shows that 85% of Taiwanese households have been equipped with an air conditioner. This indicates that most of Taiwanese residents who live in a humid and hot climate have becoming increasingly accustomed to creating a comfortable indoor environment. Nevertheless, such a solution would cause a heavier financial burden because of the increasing use of energy and is in consistent with the national objective of reducing the greenhouse gas emission from buildings. Worse still, installing an air conditioning system in houses will become a practice in the long run; consequently, the principle of passive building will disappear in the design of many residential buildings.

In the eco-friendly building mark accreditation, the way in which the issues about the indoor thermal comfort of natural ventilated buildings are handled is different from that of the buildings equipped with air conditioning where only one indoor environment assessment indicator can ensure the satisfaction of residents [Liang]. As for the former, miscellaneous indicators, including micro-climate and building, are used for the control and confirmation. Taking a house with the eco-friendly building market accreditation as the research subject, this paper described the design methods adopted by the research subject and conducted a measure-based experiment on the building, with the hope of demonstrating the effects of Taiwanese eco-friendly buildings in guaranteeing the thermal comfort of natural ventilated houses.

Methodology

The research subject was a residential building located in Taichung City in Taiwan, as is shown in Figure 1. Designed and constructed according to the principles of environment-coexisting buildings, it passed the accreditation for the Taiwanese eco-friendly building mark. According to the research objectives of this paper, only the technologies the building adopted to promote natural ventilation and reduce the use of air conditioning will be discussed.

Figure 1 Appearance of the Residential Building as the Research Subject

Planting as many trees as possible on the premises can increase the moisture content in the air and lower the air temperature to regulate the climate and create greater comfort [Ng]. Figure 2 shows the vegetation of the research subject, revealing that about 50% of the premises was covered by trees and that the trees scattered around the building. Aside from the ground vegetation, trees could also be found on the balconies of the floors and on the roof.

Figure 2 Layout of the Vegetation and Pools of the Research Subject

If premises have a stronger ability to retain moisture, they will have greater potential to reduce outdoor temperature through moisture evaporation, thus significantly alleviating a high outdoor temperature and increasing outdoor thermal comfort [Lin]. As is shown in Figure 2, the belt-shaped eco-ditches and ponds, along with an outdoor swimming pool, scattered around the building in the research subject. In particular, the water of the eco-ditches and ponds came from the rainwater recycling system.

As for the households, the higher houses had good wind speeds, so they were equipped with windows of appropriate sizing and location which could contribute to adequate cross ventilation and eliminate the heat generated indoors and the one transmitted into and stored in the room, thus maintaining the thermal comfort throughout the day. But as far as the public space on the ground floor was concerned, there weren't good wind speeds due to the trees around the building; therefore, the buoyancy driven stack ventilation must be adopted to solve the problem. In the research subject, a buoyancy driven stack ventilation system (see Figure 3) was installed in the rooms on the first floor, so that the outdoor cool and fresh air could flow towards the majority of the breathing zone.

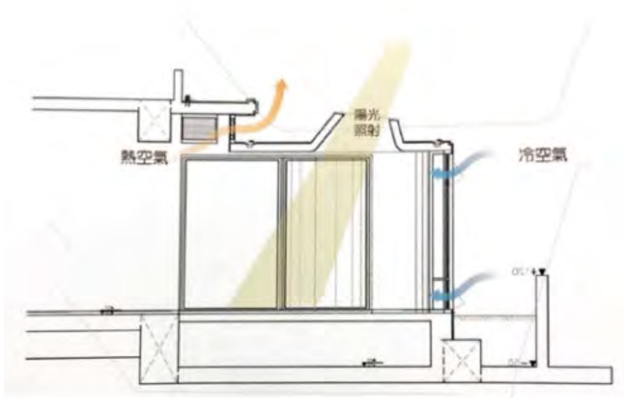

Figure 3 Diagram of the Buoyancy Driven Stack Ventilation System Installed in the Ground-level Public Space in the Research Space

Adequate window sizing was installed on the south side of the research subject so that the houses could have as much natural ventilation as possible. But the problem was that the building would face much solar radiation which would result in a high indoor temperature in warmer months. Studies [Hwang; Lyon; Chan] showed that solar radiation and the thermal performance of windows had great influence on the thermal comfort of the residents in the building's glazed perimeter zones. To avoid the problem, each house was equipped with an effective sunshade device and balcony to prevent solar radiation from entering the rooms through windows, as is shown in Figure 2. The trees lined around the building created adequate sunshade for the public space on the ground floor.

In this study, the survey was based on objective parameter measurement. The indoor parameters of the testing included air temperature and relative humidity. The measurement was conducted in the public space on the ground floor as well as in the sitting room and bedroom of a residential house on the 14th floor. The measurement lasted for two months, from October to December 2016. The period was in the season when natural ventilation was suitable for Taiwan. According to the schedule of the residents, the measurement in the public space started from 10:30 to 17:00; the one in the sitting room started from 09:00 to 19:00; the one in the bedroom started from 19:00 to 07:00. To facilitate the comparison with the indoor thermal comfort, the graphers were placed in three locations – the outdoor balcony on the 14th floor, the location outside the window of the public space on the ground floor, and the upwind outside the premises. These recorders measured the outdoor temperature during the period.

Results and discussion

Figure 4 is a comparative analysis of outdoor air temperature inside and outside the premises. The temperature difference, the horizontal ordinate of Figure 4, refers to the gap between the air temperature inside the premises and that outside the premises. As is shown in Figure 4, the vegetation and moisture retention design of the premises significantly lowered the air temperature outside the premises, so the air temperature inside the premises was always lower than that outside the premises during the measurement period. For 50% of the period, the temperature was lowered by more than 1.0℃, with an average of 1.1℃ and a maximum of 3℃.

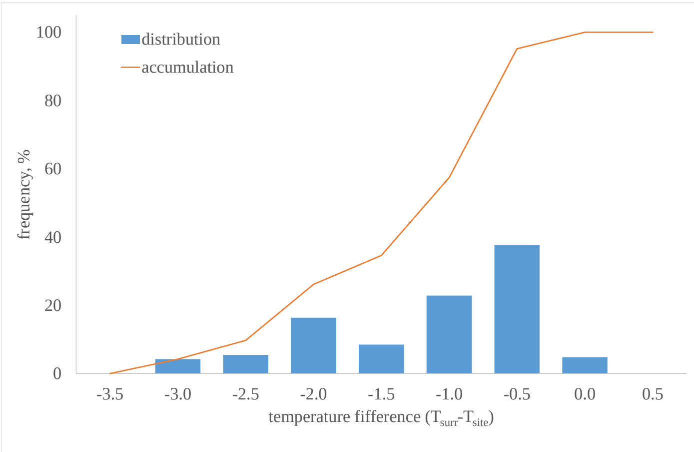

Figure 4 Comparative Analysis of Outdoor Air Temperature inside and Outside the Premises

Figure 5 shows the measurement results of the indoor temperature of the public space equipped with the buoyancy driven stack ventilation on the ground floor. According to Figure 5, the indoor temperature of the public space on the ground floor was the same with the outdoor temperature for 45% of the measurement period, and it happened after 14:00. This manifested that the buoyancy driven stack ventilation brought adequate natural ventilation to the space, so that the indoor space and the outdoor space shared the same temperature. Figure 5 also demonstrates that the indoor temperature was lower than the outdoor temperature for 55% of the measurement period. The comparison of the time of the temperature difference shows that it started from 10:30 to 14:00 and that the temperature difference was more significant in the earlier stage. The reason for the phenomenon was that the doors and windows of the space were closed before the measurement at 10:30 by which the low temperature in the previous night had not dissipated. In the public space on the ground floor, the combination of the thermal storage at night and the buoyancy driven stack ventilation during the day led to an average temperature reduction of 0.4℃ in the indoor temperature compared with the outdoor temperature in the premises.

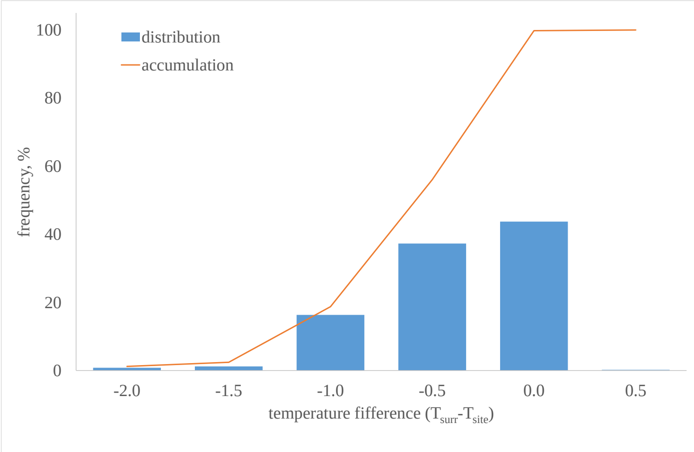

Figure 5 Comparative Analysis of the Indoor and Outdoor Temperature of the Public Space Installed with Buoyancy Driven Stack Ventilation on the Ground Floor

Figure 6 shows the results of the temperature measurement of the sitting room during the day. During the measurement, the French window of the sitting room was kept open. According to Figure 6, the temperature of the sitting room was the same with the outdoor temperature for 30% of the measurement period during the day when the French window was kept open, while there was a difference of -0.5~0.5℃ between the indoor and outdoor temperature for 67% of the measurement time during the day. Throughout the measurement period, the average temperature of the sitting room was 0.1℃ lower than the average outdoor temperature during the day.

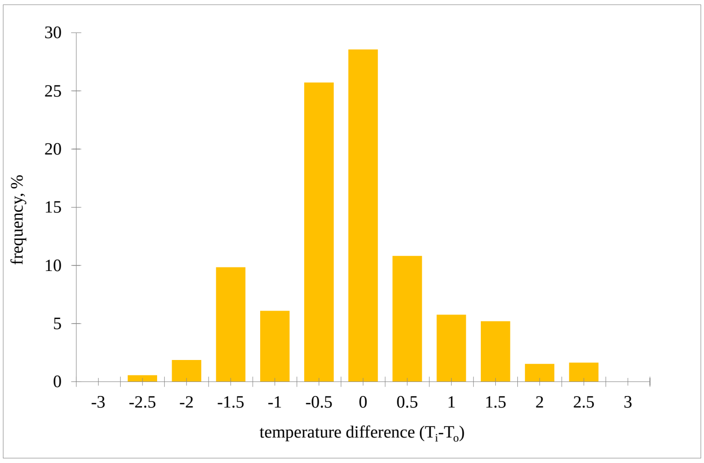

Figure 6 Distribution of the Difference between the Temperature of the Sitting Room and the Outdoor Temperature

Figure 7 shows the results of the temperature measurement of the bedroom at night. The temperature of the bedroom was the same with the outdoor temperature for 21% of the measurement period, and there was a difference of -0.5~0.5℃ between the indoor and outdoor temperature for 56% of the measurement period during the day. Throughout the measurement period, the average temperature of the bedroom was 0.1℃ lower than the average outdoor temperature.

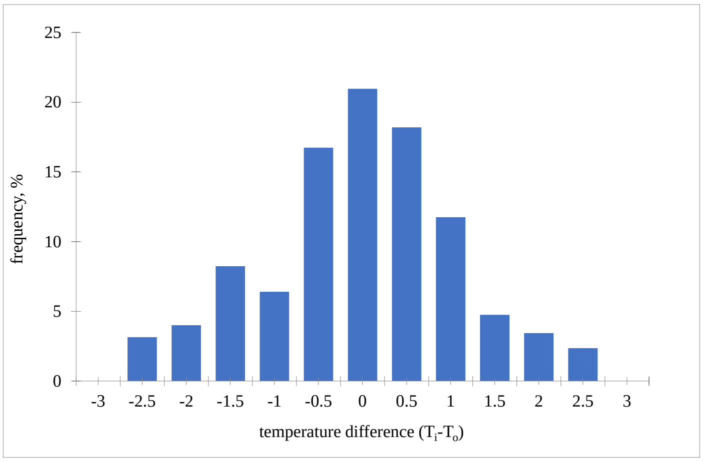

Figure 7 Distribution of the Difference between the Temperature of the Bedroom and the Outdoor Temperature

According to Figures 6 and 7, the cross ventilation design in the residential house could help maintain a temperature shared by the sitting room/bedroom and the outside environment. In other words, it is possible to maintain thermal comfort brought by cross ventilation to the indoor space of residential house in the season suitable for natural ventilation.

Conclusion

This study aims to find out if the residential houses which follow the design principles of eco-friendly buildings can meet the requirements on thermal comfort in the season suitable for natural ventilation. Through a measurement-based experiment on a building with the accreditation of eco-friendly building, this paper has demonstrated that a design featuring the combination of the vegetation and moisture retention design of the premises, the sunshade of the building, buoyancy driven stack ventilation and the cross ventilation can ensure thermal comfort in an indoor environment when the external conditions are suitable, thus reducing the use of air conditioning, energy consumption and carbon emission.

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Sky view factor as predictor of solar availability on building façades: using the case of London

Christina Chatzipoulka[1, 2], Raphaël Compagnon[1] and Marialena Nikolopoulou[2]

[1] Haute Ecole d'ingénierie et d'architecture de Fribourg (HEIA-FR), Fribourg, Switzerland
[2] Kent School of Architecture, University of Kent, Canterbury, United Kingdom
Correspondence email: chatzipoulka@gmail.com

Abstract: Sky view factor (SVF) measures the openness of a point to the sky vault and as such, has been widely used in urban climatology and environmental design studies associated to various phenomena, including Urban Heat Island intensity and daylight availability. This study examines to what extent SVF can be also employed for predicting solar availability in the urban environment, with emphasis on building façades.
SVF and solar irradiance simulations were performed for vertical façades in 24 urban forms -of 500x500m area- in London; mean values were computed by urban form, and by façade orientation, considering 30 orientations at 12° azimuth intervals. The statistical analysis reveals a strong linear relationship (R^2>0.8) between SVF and annual global irradiance for all orientations. The models derived from linear regression tests were integrated into a graphical tool for predicting annual global irradiance on a façade in London as a function of its SVF and azimuth angle. Furthermore, the fact that SVF was found to correlate well with both major components of solar irradiation, namely direct and sky diffused irradiances, indicates that it can be used for predicting annual solar availability at latitudes similar to London, even for sunnier climates.

Keywords: solar potential, solar indicator, sky view factor, urban façades, orientation

Introduction

Solar energy is one of the renewable energy resources with the greatest potential; it is estimated that, upon certain conditions, solar energy could contribute to 27 per cent of the global electricity production by 2050 (IEA, 2014). Unlike other renewable energy technologies, photovoltaic (PV) systems can be relatively easily applied in the urban environment, integrated into new and existing buildings. A major advantage of exploiting building envelopes for harnessing solar radiation is the on-site production and use of energy which will be a requirement for all new buildings in the European Union after 2020 (EPBD, 2010).

Compared to façades, roofs are regarded more favourable for the implementation of photovoltaic systems as there they are generally less affected by overshadowing and intervene less with buildings' appearance and other functions served by façades (daylighting, natural ventilation, etc.). Nonetheless, with façades comprising the greatest part of urban buildings' surface, their solar irradiation represents a considerable percentage of cities' solar energy potential (Redweik et al., 2013) and hence, their exploitation becomes critical for the attainment of energy efficiency targets at building and urban scale. In response to this challenge, photovoltaics technology is advancing rapidly offering more possibilities for an improved architectural integration, aesthetically (colours, level of transparency, etc.) and functionally (e.g. providing solar and glare protection).

The potential for integration of PV systems on façades varies significantly in urban areas, as façades' insolation is highly sensitive to urban geometry, affected by orientation and degree of obstruction (Esclapés et al., 2014; Yun and Steemers, 2009). The orientation of an unobstructed façade determines its interaction with the solar geometry at a specific location and thus, its potential solar irradiation. However, urban façades are usually obstructed by surrounding buildings which limits their openness to the sky (related to the sky diffuse solar component) and solar exposure (related to the direct solar component). Past studies, employing statistical analysis, have shown a strong negative relationship between degree of sky obstruction, associated positively to built density, and façades' total solar irradiation (Chatzipoulka et al., 2016; Mohajeri et al., 2016). However, their findings refer to average values over entire urban areas, neglecting the orientation parameter.

This study explores the relationship between the degree of sky obstruction, expressed by sky view factor (SVF), and solar availability on building façades as a function of their orientation. Initially introduced by urban climatologists, sky view factor (SVF) is a measure of the openness of a point to the sky and thus its capability to emit and receive longwave radiation to and from the sky, respectively. In the literature, SVF is equally used as urban geometry variable, e.g. investigating its relationship with spatial variations of urban air and surface temperatures (Eliasson, 1996; Yamashita et al., 1986), and as performance indicator evaluating environmentally different urban forms (Project PREcis, 2000; Ratti et al., 2003). With respect to façades' performance, SVF is widely used as indicator of daylight availability (e.g. Cheng et al., 2006; Zhang et al., 2012), whereas its relation with solar availability is less established.

In the past, SVF measurements were feasible only in situ and at one point each time, using special equipment such as fish-eye cameras. Nowadays, an increasing number of urban solar and thermal analysis models perform accurate SVF calculations as part of their simulations, over entire urban surfaces and at different spatial resolutions. Compared to solar irradiance simulations, the calculation of SVF is faster and requires solely one input, namely the 3D urban geometry information. In this context, predicting solar availability in urban environments using SVF values would enable a quick evaluation of solar energy potential and facilitate the task of architects and urban designers for integration of efficient solar active strategies in new and existing buildings.

Methodology

Cases studies

This study is part of an on-going research and based on the analysis of twenty-four urban forms, of 500x500m area each, which have been selected from three areas of London. These areas represent urban environments of different built density with the studied urban forms covering values from 3 to 22, m^3/m^2 (total built volume within the site over site area). The results of their geometrical analysis as well as the criteria for their selection are presented analytically in Chatzipoulka et al. (2016). It is noted that the naming of the urban forms as appeared in Figure 1 is reserved for consistency between past and future publications: the letter denotes the area to which an urban form belongs (C, W, N for central, west, north area, respectively), while the number derives from its position in the area's map.

Figure 1. Ground maps of twenty-four urban forms considered in the analysis, in decreasing order of density.

SVF and solar irradiance simulations

Solar simulations have been performed in PPF software, a powerful tool which has been employed by several studies, so far (e.g. Chatzipoulka et al., 2016; Cheng et al., 2006; Project PREcis, 2000). PPF is based on the RADIANCE ray-tracing programme (Ward Larson and Shakespeare, 1998) and uses sky models which represent average radiance distributions of the sky vault for a given time period (Compagnon, 2004). Specifically, for the irradiation simulations, climatic data of London (hourly direct and diffuse irradiance values) were obtained from METEONORM software (Remund et al., 2015) and processed statistically in order to build up London's annual sky model (Fig. 2a). Only daytime hours were considered, i.e. hours between sunrise and sunset on a day, which are 4317 in total. It is worth to be mentioned that, considering the entire year, direct and diffuse horizontal irradiance for London are in a relative balance with the former being 102 and the latter 120, W/m^2.

The 3D digital models of the urban forms were reproduced in a CAD software, including the surrounding buildings, and inserted in PPF (Fig. 2b). Annual mean irradiances [W/m^2] and sky view factor (SVF) [-] values were computed on a grid of 2-meter spatial resolution, adjusted onto the surfaces of the models. Direct (*Id*), diffused from the sky (*Is*) and reflected by buildings (*Ib*) irradiances were computed separately; while global (*Ig*) irradiance is calculated as the sum of them, as described below:

$$Ig = Id + Is + Ib$$

SVF ranges from 0 to 1, denoting a totally obstructed and unobstructed point, respectively; however, façades' SVF value ranges from 0 to 0.5 as unobstructed vertical surfaces can be seen only by half of the sky vault.

The simulation results were processed in Matlab and mean values of four types of irradiances and SVF were computed, first by urban form, and next by orientation in each urban form. The relationships between mean SVF and irradiances were next explored performing linear regression analysis in the same programme.

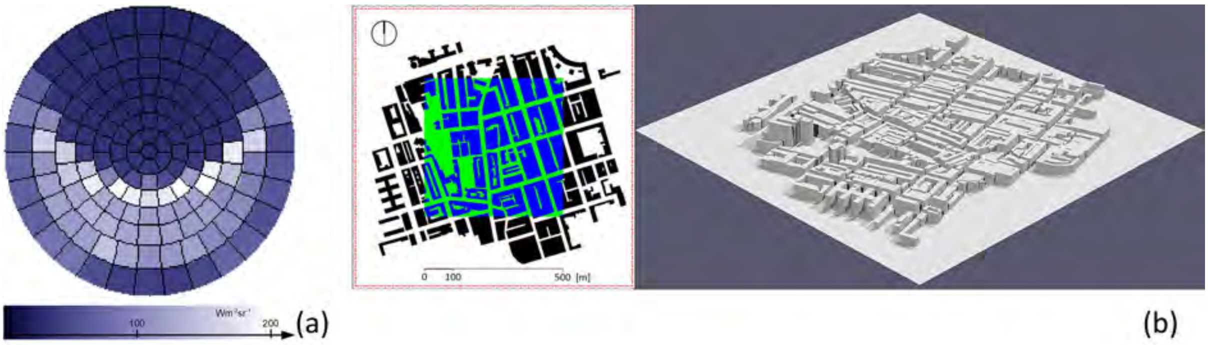

Figure 2: (a): Stereographic view of the sky vault representing London's annual sky model used for irradiance simulations. (b): Left, ground map of C2 urban form, in colour the simulated area and in black the surrounding buildings; right, its perspective view in PPF.

Results

Mean façade SVF and irradiances by urban form

Figure 3 illustrates annual mean irradiances and mean SVF values computed for each of the 24 urban forms, ranked (from left to right) in decreasing order of density. As implied by the line chart, the relationship between mean façade SVF and density is clearly negative with the coefficient of determination (R^2) being 0.92. The colour bars allow the comparison of the percentages in which annual global irradiance consists of direct, sky diffused and reflected irradiation. It is ascertained that, in all the urban forms, façades' annual global irradiance consists constantly of direct radiation by 42-43%, sky diffused by 44-45% and reflected by 13-14%. Hence, sky diffused radiation constitutes the greatest part of annual irradiation received by building façades in London, with direct solar contribution though being equally important.

The linear regression analysis revealed a particularly strong, positive correlation between SVF and all three irradiances comprising global irradiance (R^2>0.98) and so, not surprisingly, the relationship between SVF and global irradiance was found to be almost perfectly linear (R^2=0.99). It is pointed out that, since global irradiance expresses the sum of three irradiance components, its statistical relationship with SVF is determined by the relationship of each of its components with SVF, weighted by their percentages.

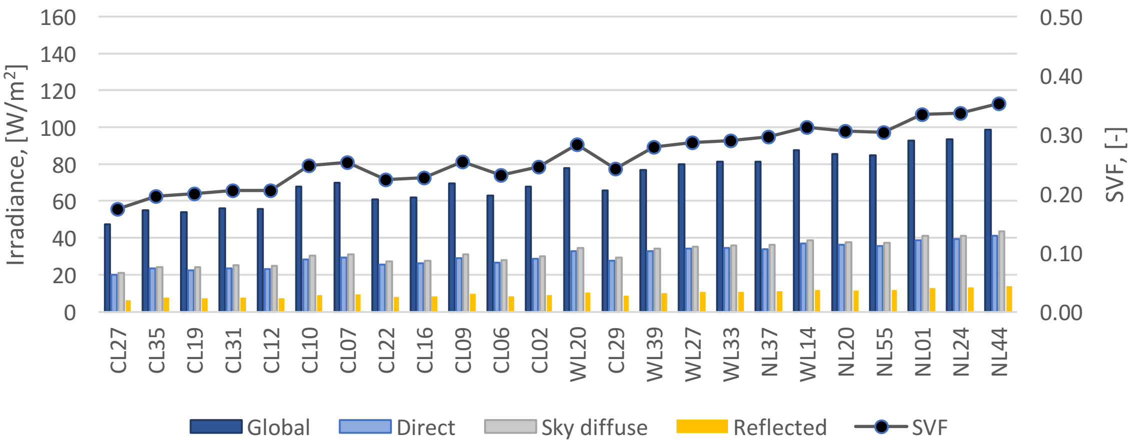

Figure 3. Mean façade SVF (dots, right vertical axis) and annual global, direct, sky diffused and reflected irradiance values (bars, left vertical axis) by urban form.

Mean façade SVF and irradiances by orientation

In the previous section, average façade SVF and irradiance values in the urban forms were found to correlate particularly highly, independently to type of irradiance. Nonetheless, solar availability on building façades and, especially the direct solar radiation received by them, is strongly affected by their orientation in relation to the sun path. Thus, the averaging of solar irradiance values over entire urban forms may suppress significant variations of the studied relationships occurring at different orientations. For this reason, the relationships between mean façade SVF and irradiances were also examined by orientation, considering 30 orientations at 12° azimuth intervals; these represent the patches into which the perimeter of the sky models is divided (see Fig. 2a). The numbering of the orientations starts from North (Orientation 1: -6 ≤ azimuth < 6) and counts clockwise.

Once mean SVF and irradiances were computed for all 30 orientations by urban form, the obtained values were classified by orientation. In total, 120 regression analysis tests, i.e. 30 orientations by four types of irradiance, were performed. For some orientations, the regression was based on less than 24 cases as some urban forms present very few points (<10) facing at specific orientations. In all cases though, the number of urban forms considered were not less than 20.

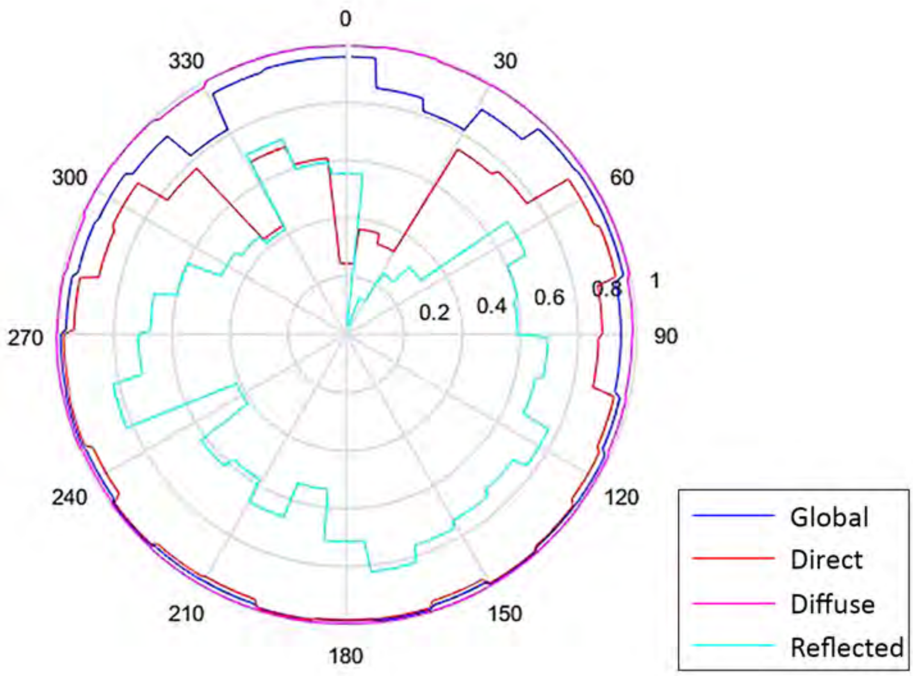

Figure 4. Variations of R^2 -measured from centre outwards- describing the linear relationship of SVF and annual mean irradiances, i.e. global, direct, diffuse, and reflected, by orientation.

The R^2 describing the strength of the relationship between mean SVF and annual irradiances are presented graphically in a polar chart in Figure 4, with the values being measured from the center outwards. As may be expected, the relationship between SVF and sky diffused irradiance is found to be almost perfectly linear for all orientations. Regarding direct irradiance though, the relationship is clearly affected by orientation: it is significantly strong (R^2>0.8) for façade azimuths between 60° and 300° (from East to West) whereas, for the remaining orientations, the R^2 values are reduced and vary unevenly. This may be partially attributed to low solar altitudes coinciding with north orientations (Chatzipoulka et al., 2015). On the other hand, the relationship between SVF and irradiance reflected by buildings appears to be independent to orientation as the R^2 fluctuates unevenly around different orientations. Finally, regarding global irradiance, it is of great interest that the R^2 value is constantly above 0.8. This is explained by the following: (i) the reflected part comprises a small percentage of the total irradiance received by building façades, and (ii) the solar irradiation of façades facing to north orientations is dominated by sky diffused radiation.

Predicting annual global irradiance on façades in London

Since mean façade SVF presents an almost perfectly linear relationship with annual mean global irradiance, independently to orientation, it is argued that SVF can be used as a good predictor of solar energy potential of façades. This section provides a graphical tool to architects and urban designers based in London for estimating annual global irradiance on a façade, as a function of its orientation and mean SVF. For this purpose, linear regression analysis was repeated setting intercept value to zero and 30 analytical models i.e. one for each orientation, were obtained; the beta coefficients (b) are presented in Table 1. As shown in Figure 5, which demonstrates the scatter plots and linear resolutions for six representative orientations, setting intercept to zero affects slightly the strength of the relationship with R^2 remaining significantly high.

The linear functions were next solved for 10 representative SVF values, from 0 to 0.5, at 0.05 intervals, and the (x, y) points are plotted on Cartesian axes as continuous curves. The relevant graph is presented in Figure 6; the suggested way of using it is as follows:

- identify the azimuth degree of the façade of interest on the horizontal axis;
- from that point, draw a normal line to intersect the curve representing SVF value closest to mean SVF of the façade;
- project the intersection point on the vertical axes to read the estimated annual mean global irradiance [W/m^2] (left) and solar irradiation [kWh/m^2] (right).

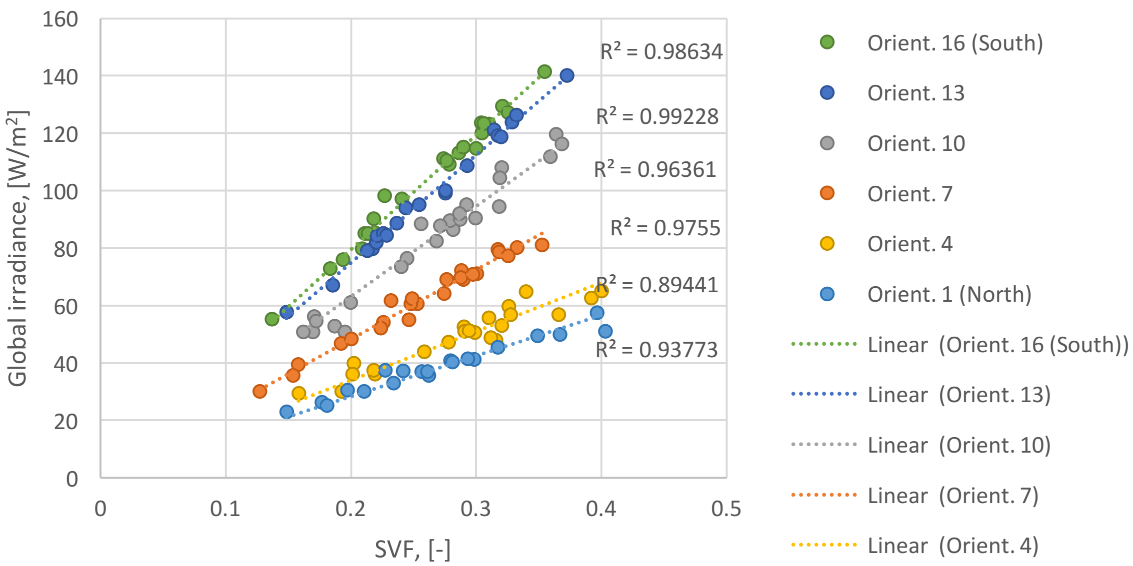

Figure 5. Mean global irradiance plotted against mean SVF values for six representative orientations, and their linear regression by setting intercept value to 0.

Table 1: Coefficients (b) for estimating annual global irradiance (Ig) as function of SVF for all different orientations, where Ig = b * SVF.

azimuth, a [°]	North: -6 ≤ a < 6	Orient. 2: 6 ≤ a < 18	Orient. 3: 18 ≤ a < 30	Orient. 4: 30 ≤ a <42	Orient. 5: 42 ≤ a < 54	Orient. 6: 54 ≤a <66	Orient. 7: 66 ≤ a < 78	Orient. 8: 78 ≤ a <90	Orient. 9: 90 ≤ a < 102	Orient. 10: 102≤a <114
b	141.95	143.54	150.96	169.94	190.93	215.41	241.5	264.72	291.80	315.55
azimuth, a [°]	Orient. 11: 114≤a <126	Orient. 12: 126≤a <138	Orient. 13: 138≤a <150	Orient. 14: 150≤a <162	Orient. 15: 162≤a <174	South: 174≤a <186	Orient. 17: 186≤a <198	Orient. 18: 198≤a <210	Orient. 19: 210≤a <222	Orient. 20: 222≤a <234
b	338.2	355.6	374.51	388.2	394.56	398.49	398.36	392.70	382.10	367.65
azimuth, a [°]	Orient. 21: 234≤a <246	Orient. 22: 246≤a <258	Orient. 23: 258≤a <270	Orient. 24: 270≤a <282	Orient. 25: 282≤a <294	Orient. 26: 294≤a <306	Orient. 27: 306≤a <318	Orient. 28: 318≤a <330	Orient. 29: 330≤a <342	Orient. 30: 342≤a <354
b	345.46	321.44	302.34	276.18	243.38	213.78	193.56	172.76	154.06	145.06

To test the validity of the prediction models, annual global irradiance was computed on the facades of a single, unobstructed building of triacontagonal plan (i.e. featuring 30 façades, pointing at the middle of orientation intervals). Comparing the results with values derived by solving the models for SVF equal to 0.5 - represented by the upper, light blue curve in Figure 6 -, it was found that the latter tend to slightly overestimate façades' annual global irradiance; however, there is still a very good agreement. Indicatively, the relative difference between values derived from the models and those simulated for the test is on average 3.7%, and the greatest differences, about 6.5%, are observed for façade orientations receiving annually more solar radiation, i.e. south orientations.

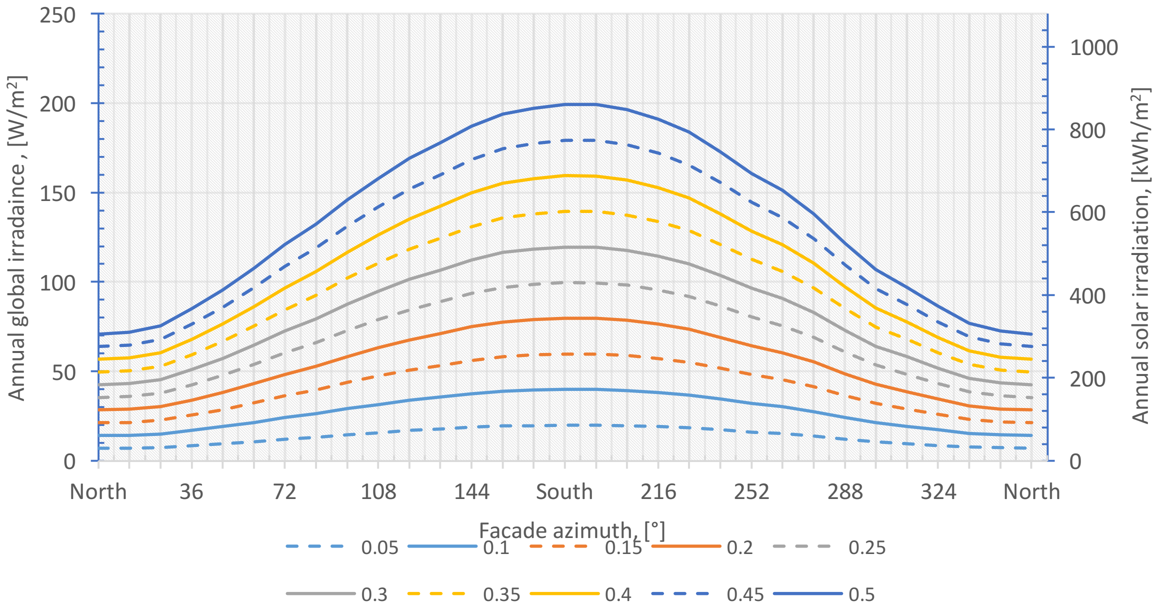

Figure 6. Graphical tool for estimating annual global irradiance on (left) and solar irradiation of (right) a vertical surface in London, as a function of its azimuth angle and mean SVF.

Conclusions and further research

Evaluating solar energy potential of façades using their SVF values would be of great relevance to professionals working in the field of urban environmental design. SVF is exclusively defined by urban geometry and thus its calculation is more straightforward compared to solar simulations. Using the case of London, the present study demonstrates that this is feasible since SVF was found to have a strong linear relationship with annual global irradiance, independently to façade orientation. To exemplify the usability of such a finding, the linear models obtained from regression analysis are integrated into a graphical tool for predicting annual solar irradiation of a façade surface, based on its SVF and azimuth angle.

Additionally, the fact that SVF was found to correlate well with both dominant components of solar irradiation, namely sky diffused radiation and direct radiation for major orientations (i.e. azimuths described by the annual sun path), indicates that SVF can be used as a predictor of annual solar availability at latitudes similar to London, even for sunnier climates. To test the sensitivity of the findings to other time periods and latitudes, the analysis has been extended to a winter month, January, and a summer month, July, considering two more European cities, Athens and Helsinki. Overall, the results confirm the strong relationship between SVF and solar irradiation of facades, and are reserved for a future publication.

Acknowledgements

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Free-running High Rise Housing in Hot and Humid Climates – issues and solutions

Drin Chulakasyena[1] and Paula Cadima[2]

[1] Sustainable Environmental Design, Architectural Association School of Architecture, London, drin.chulakasyena@aaschool.ac.uk
[2] Sustainable Environmental Design, Architectural Association School of Architecture, London

Abstract: Bangkok is one of the world's hottest and most humid cities. Its high rise residential developments currently depend on air conditioning to provide acceptable thermal comfort. This paper reports to the results of research carried out to establish guidelines towards free-running high rise buildings in this climate.
Fieldwork on existing buildings identified that opportunities for ventilation were commonly inadequate, with negative impacts on both temperature and humidity. Balconies were ubiquitous, but were little used due to design shortcomings. Examination of internal walls and divisions identified problems of inadequate soundproofing and insufficient separation of hot and odorous kitchens from other living spaces.
Solar control studies demonstrated that a combination of fixed horizontal and vertical shading devices and adaptive horizontal louvres could help address issues of excessive direct and diffuse solar radiation. Re-imagining building forms helped decreasing indoor temperature through improved cross ventilation. Further studies to assess the performance of an optimised model showed that a façade made of a combination of high thermal mass (concrete) in the living areas and lightweight material (timber) in the bedrooms improved thermal performance and users comfort. The combined results provide a basis for free-running designs for high rise residential buildings in the hot and humid Bangkok.

Keywords: free-running, hot and humid, solar control, cross ventilation, thermal mass.

Introduction

High rise developments in Bangkok are commonly designed with single aspect apartments and double load corridors, in either linear or L-shape, with large glazed areas, no shading devices and with a balcony inset into the façade of every unit. The potential for cross ventilation is very limited.

Most of this housing scheme replicates cold-climate models with sealed façades and relies very heavily on air conditioning engendering a wide range of environmental impacts. This is at odds with traditional living patterns in the tropics, where light winds, year-round mild weather, and fairly constant temperatures make outdoor living desirable. At the same time the obvious constraints of high rise construction, and of air pollution and noise in the city, limit the potential for the outdoor lifestyle that previous generations enjoyed. That said, there seems clear potential to design better performing buildings that would both improve environmental performance and work in better harmony with the climate.

Balconies are an almost omnipresent feature of high rise residential buildings in Bangkok and offer the greatest opportunity for connecting the occupants with the exterior environment. But recent research shows that the design of most existing balconies is such that they are little used other than for storage, drying clothes and as a location for installing air conditioning condenser units (Chulakasyena, 2016).

High demand and limited regulatory control can result in buildings whose design focus is on fast and low cost construction, often with lip service at best to environmental issues. As the market matures there is opportunity to promote the benefits of a greater focus on sustainable design, delivering not only better environmental performance but long term cost savings.

The aim of this paper is to establish design guidelines for achieving free running high-rise residential buildings in Bangkok, while maintaining or improving occupant's comfort and satisfaction within their dwellings.

Climate analysis and comfort band

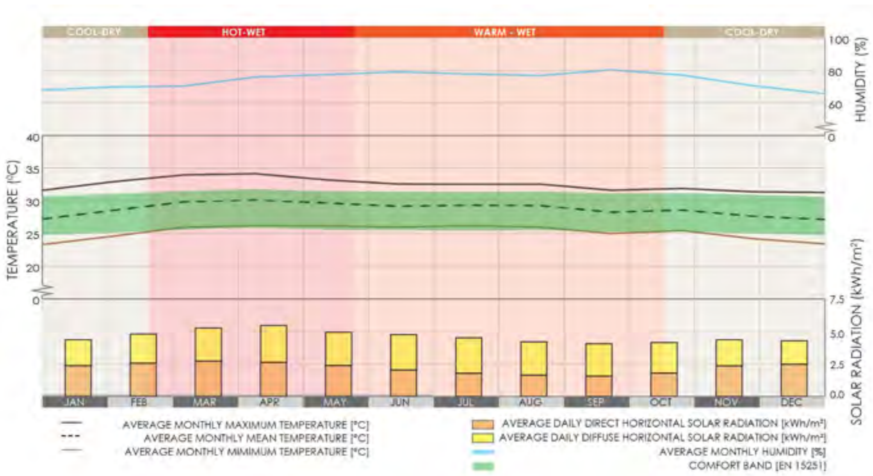

Fig. 1. Bangkok (Don-Muang airport) weather data with the EN 15251 comfort band (Source: Meteonorm 7.0)

Designing with the local climate highlights the need for enhancing ventilation and for reducing the impact of solar radiation, both direct and diffuse, while maintaining levels of daylight is desirable, (Fanger 1993, Koch-Nielsen 2002 and Givoni 1994). The thermal comfort criteria set out in EN 15251 correspond closely to those found in recent studies in Bangkok (Taweeken 2013, Jitkhajornwanich 2006) and will therefore be used for assessment purposes, Fig. 1.

Fieldwork

Fieldwork was carried out in two apartments, one at the *Rhythm* and another at the *U-Delight* building in Bangkok, (Chulakasyena, 2016). The *Rhythm* building has an enclosed, glazed lobby area, as is common in upmarket residential buildings, Fig. 2(a), while the *U-Delight* building has an open space that functions both as a lobby and playground area, Fig. 2(b). The fieldwork confirmed that ventilation in the apartments studied is inadequate. During the times visited there was a minimal air movement inside the lobby in the *Rhythm* building and a nearly consistent 1-2 m/s wind velocity within the ground floor of the *U-Delight* building.

Fig. 2. Lobby area in *Rhythm* building (a) and in *U-Delight* building (b).

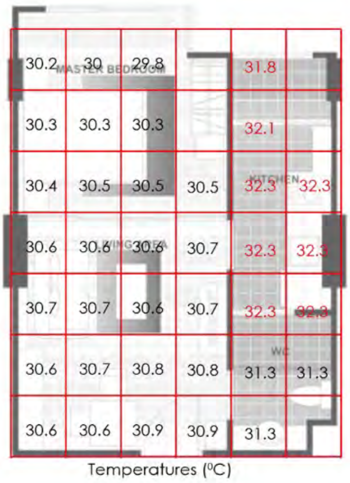

Fig. 3. spot measurements (temperature)

The indoor air temperature in the kitchen of a representative apartment was consistently almost 1.5K higher than in the bedroom and (linked) living room, Fig. 3. The higher temperature in the kitchen seemed likely to be due to the heat output of the refrigerator. This effect, together with the additional heat gain in the kitchen from cooking (and associated smells) suggested that separating kitchen and living areas is highly desirable.

In summary, the fieldwork studies confirmed practical issues related to the impact of solar radiation and poor potential for ventilation, and also drew attention to the internal layout, location of kitchens and usability of balconies.

Analytical work

Analytic work was carried out to assess the impacts of solar control, building form, natural ventilation, materiality and occupancy on environmental performance (visual and thermal), as well as of the balcony design in order to increase air movement. The base model, best thought to represent the typical construction and dimensions of a one-bedroom apartment in high-rise residential building in Bangkok, was assumed to be facing South with single glazing transmittance of 0.88. All other constructions details were considered to be identical with the fieldwork unit at the *U-delight* building to ensure a well calibrated model. *OpenStudio and*

Energy+ software were used for thermal simulations, *DIVA* for daylighting, *Autodesk Flow Design* for wind flow and *Grasshopper* for solar analysis.

Fixed Shading device

In order to help controlling solar radiation, a fixed horizontal shading device with 0.5m extension was tested. This is the maximum dimension allowed by National Regulations (regulation 55 section 43), therefore thought to better reflect the commercial realities of buildings in Bangkok, Fig. 4.

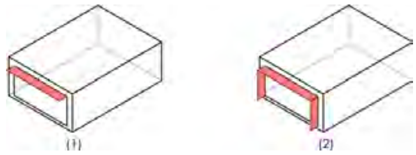

Fig. 4. 0.5m fixed shading devices – (1) Horizontal, (2) Combined Horizontal and Vertical

The analytic work showed that a fixed horizontal shading device on a South facing façade helped reducing around 80% of the direct solar radiation and almost 1.4K of the peak air temperature. On the East and West facing façades the reduction on direct solar radiation was around 25% and decreased by 0.9K the peak indoor air temperature. As expected, a fixed shading device on a North facing façade had very little effect on the air temperature (less than 0.1K).

The graph in Fig. 5 shows that adding a vertical shading to the East and West orientations reduces the incident direct solar radiation by approximately 5%, 13% to the South orientation and by 27% to the North orientation.

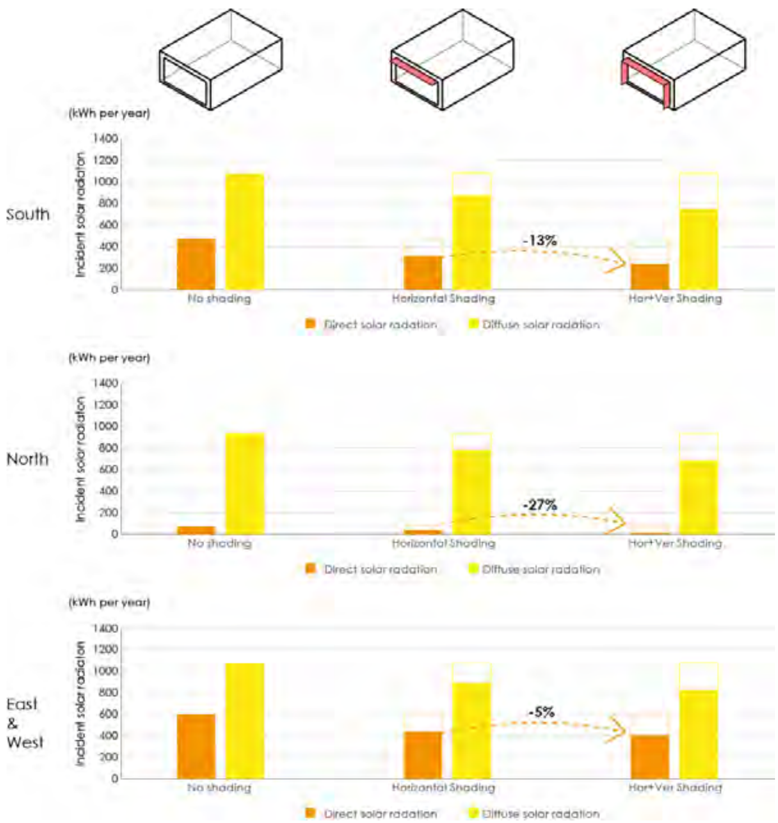

Fig. 5. Incident yearly solar radiation at various orientations with a fixed horizontal and a fixed horizontal + vertical shading devices.

Adaptive shading device

The effects on both thermal and daylighting performance of three different solar control design solutions were tested, Fig. 6: Vertical louvres (1), Horizontal louvres (2) and Combined vertical + horizontal louvres (3).

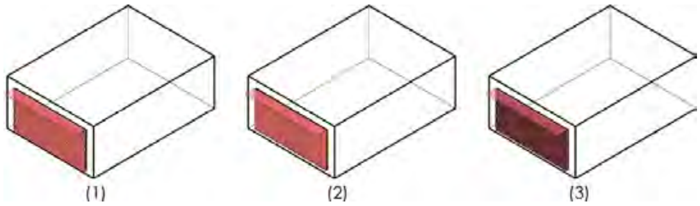

Fig. 6. Types of adaptive shading devices

Thermal Studies:
The amount of incident diffuse radiation on a South facing window is decreased by 33% with horizontal louvres and by 39% with vertical louvres, while combining horizontal and vertical louvres decreases 50%. Shading with any of these louvre types decreased by 0.3-0.4K the indoor air temperature. The studies show that on the East and West facing windows horizontal and combined horizontal with vertical louvres deliver the best performance, reducing both diffuse and direct radiation by up to 70% for East orientation and 61% for West orientation, while decreasing the indoor air temperature by almost 2K on a hot day.
The use of louvres on North facing windows is poorly justified as there is minimal reduction in the indoor air temperature. Nevertheless, this would help decreasing the diffuse solar radiation between 29% (horizontal) to 47% (combined).

Daylighting Studies:
In terms of visual performance, the combined solution is shown to deliver the best reduction in glare, although horizontal louvres provide the best results for daylighting distribution (for all orientations). Vertical louvres are the least advisable design strategy to control glare and provide a good daylighting distribution.

Building form

The climate analysis indicates that in Bangkok it is desirable to have building interior spaces coupled with outdoor temperature, as for most of the time the outdoor temperature is within the comfort band, especially during the night and rainy periods. The most efficient way to achieve this coupling is to provide cross-ventilation. This in turn requires openings on more than one façade. Three alternative forms were tested in models representing apartment unit with two, three and four external walls, respectively.

The typical construction materials used usually have low insulation properties (concrete wall), therefore increased external wall area and thus more exposure to the outdoor atmosphere will also help dissipate excess internal heat gain by convection.

Daytime temperatures drop by 1-2K for all variants (2, 3 and 4 external walls). Night time temperatures drop by 1-1.5K for 2 walls, 2.5-3K for 3 walls and 3-3.5K for 4 walls (the drop in night time temperature naturally has an impact on day time temperatures, as the starting temperature is lower). The tests exclude the effect of natural ventilation; so once that is factored; it would further reduce the air temperature in the models with 3 and 4 exposed walls, in particular during night time.

Natural ventilation

The matching square openings with an area of 1 m² allow ventilation rates of 5 to 40 ac/h. If the shape of the outlet were to be changed to a landscape rectangle with the same opening area made, there would be no meaningful difference.

The studies showed that providing larger openings of equal area provides the best results. With an enlarged inlet opening area to 3 m^2, the number of hours with ac/h above 15 increased by 47%. Enlarging both inlets and outlets to 3 m^2 the percentage of time with a rate of 15 ac/h or above can further increase by 75%.

Materials

Analytic results indicate that exposed high thermal mass combined with a ventilation rate of 15 ac/h, can help decreasing the daytime indoor temperature to within the comfort band. However, there is a slight temperature increase at night, a time during which lower temperatures are desirable for sleeping. This leads to the conclusion that the high mass strategy is appropriate for living areas used during the day, but lightweight materials perform better in the bedrooms, enabling the room temperature to couple more closely with the decreasing outdoor air temperature.

Occupancy

Predictably, the temperature rises both day and night with increased levels of occupancy, but by only around 0.1 - 0.2 K with four occupants. The high ventilation rate and the high thermal mass may help dissipating and to absorbing, respectively, the internal heat gains.

It was identified that the most effective strategy for lowering indoor temperatures when occupants are at work during the day is to leave the windows open all day. It was, however, also hypothesised that if occupants are present during the day they should close the windows when the outdoor temperature is above indoors. Results confirm that a reduction in daytime temperature of between 0.5-1.2K can be achieved this way, most prominent on the hottest day, Fig. 7. When the outdoor temperature exceeds the indoor temperature, the use of a fan providing air movement, can help further reducing the perceived temperature.

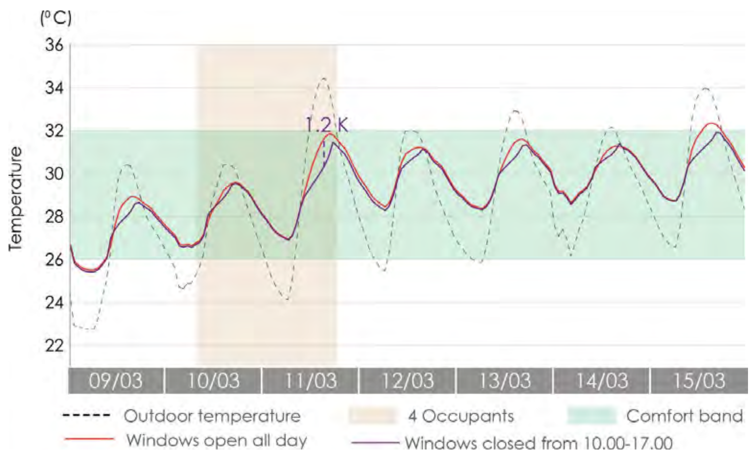

Fig. 7. Optimised model with windows open all day compared to windows closed from 10.00 – 17.00.

Balconies

The focus of this section is on enhancing ventilation on the inset type balcony, through the use of wing walls, Fig. 8, to create pressure differentials and thus increase air movement.

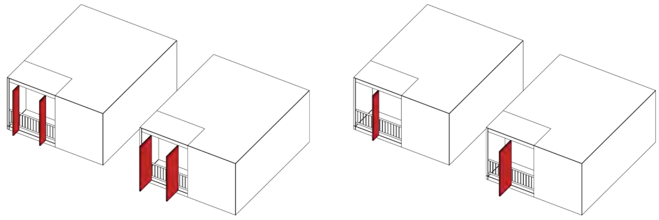

Fig. 8. Variations wing wall configurations.

Scenarios with the prevailing two wind directions in Bangkok were considered. These are perpendicular to the panels and at 45° to them. A wind velocity of 2.2 m/s was assumed, representing the average unobstructed wind flow in Bangkok.

The overall best performance is achieved by a 1m deep single panel. If this solution is excluded by regulatory considerations, the second best overall option is 0.5m deep twin panels. Limitations of the software and the real world variability in wind direction and velocity mean that the results must be viewed as indicative only, but they nonetheless helped identifying the most promising configurations of wing walls which can deliver enhanced ventilation to balconies.

Conclusion

Analytical work identified that fixed horizontal shading devices of 0.5m depth (which fall within regulatory limits) provide meaningful benefits on all building orientations, Fig. 9. Vertical shading on South and North facing windows is beneficial, although its benefits must be weighed against its potentially negative impact on lateral views, Fig. 9. Adaptive horizontal louvres can effectively address issues of excessive direct and diffuse solar radiation and daylighting in all orientations, Fig. 10.

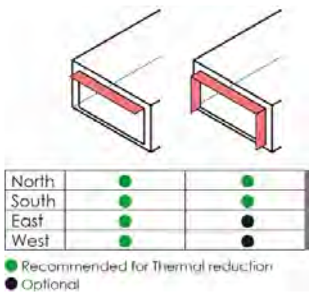

Fig. 9. Proposed fixed shading devices.

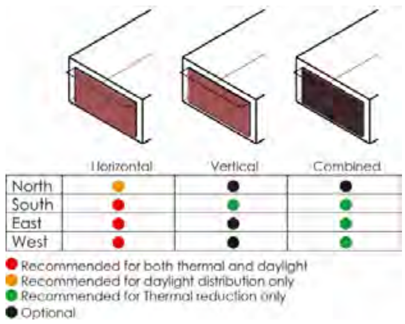

Fig. 10. proposed adjustable fixed shading devices.

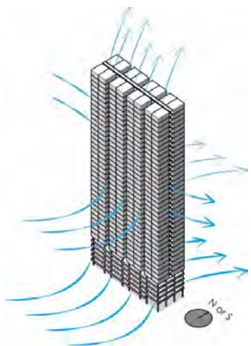

Fig. 11. Example of Proposed building form

Moving away from common monolithic building forms to apartments with three exposed walls was found to greatly increase the potential for cross ventilation, Fig. 11. Moreover, increased exposed surface also gives a greater flexibility for internal layout and openable glazing in kitchens, improving daylighting and the dissipation of indoor heat and odours.

Ventilation strategies are best with large and equal opening areas on both inlet and outlet sides.

Internally, exposed surfaces of high thermal mass were found to help reducing the air temperature in the living areas occupied during the day, while in bedrooms surfaces of low thermal mass were identified to work better, allowing a faster drop of the indoor temperature at night.

As expected, occupancy increased the internal temperature to rise, but the studies showed this to be minimal within the improved model, presumably as a consequence of the proposed ventilation strategy.

The installation of twin wing walls 0.5m deep on the balcony provides enhanced ventilation in real wind conditions and can further improve thermal comfort and its usability.

The optimised model combining all the strategies developed to drop the indoor air temperature showed a reduction on indoor temperature of up to 5.5K (on both the hottest day and night tested periods), indicating that the internal temperature can fall within the target comfort zone for all except the most extreme conditions. Even such exceptional conditions could be rendered acceptable by the use of electric fans, to create additional air movement and reduce the perceived temperature.

Overall, the study demonstrates that high rise apartments can be free-running in a hot and humid climate with simple strategies and a careful design.

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Summer performance of certified passive houses In Temperate Maritime Climates

Shane Colclough#, Neil Hewitt, Philip Griffiths

Centre For Sustainable Technologies, Ulster University, Newtownabbey, Co Antrim, BT370QB, UK. # Correspondence email address - s.colclough@ulster.ac.uk

Abstract: The solar resource in Temperate Maritime Climates (TMC) can make a significant contribution to space heating demand given the relatively long space heating season, but is this at the cost of summer overheating? This paper reviews the recorded performance of the certified passive houses with contemporaneous houses built to the minimum building regulations in Northern Ireland. The metrics being gathered at five-minute intervals for the houses are analysed: a) occupancy profile; b) indoor air temperature; c) indoor relative humidity; d) indoor carbon dioxide concentrations; e) outdoor temperature; f) outdoor relative humidity; g) wind speed; h) barometric pressure; i) energy consumption. In addition “soft” data was also gathered on the inhabitants’ perception of indoor air quality, comfort levels, heating costs etc. for both the passive and non-passive houses. *Results & Conclusions.* The key metrics are reported upon. In addition to the higher recorded temperatures of the passive houses, it is also seen that the average carbon dioxide concentrations are more uniform in the passive houses compared with the houses complying with the minimum building regulations. Further investigation is needed, however the possibility of high CO_2 readings due to insufficient ventilation (compared with the forced ventilation system of passive houses) is targeted for further investigation as part of the ongoing monitoring project.

Keywords: Passive House, Passivhaus, overheating, IEQ, IAQ

Introduction

As the prevalence of low-energy and near Zero Energy Buildings (nZEB) (e.g. Anon 2012) increases, focus is turning to the potential for summer overheating (e.g. PHI, 2014, McGill et al 2015, 2017) and means of controlling overheating (e.g. Colclough 2011). This paper presents an assessment of four of the seven NI (Northern Ireland) certified newbuild Passive Houses (PH) (PHI, 2017) in addition to five houses built to comply with the minimum building regulations standard (B Regs). This represents a subset of the dwellings being monitored as part of a study of energy consumption and Indoor Environmental Quality (IEQ) of houses on the island of Ireland (see figure 1).

Installation of monitoring equipment in the living rooms and master bedrooms commenced in May 2016 for the nine Northern Ireland houses depicted in Table 1 and data is presented here for the period to March 2017. An analysis has been carried out to determine the performance of the passive houses (PH) compared with those complying with the minimum building regulations (B Regs) over the summer and winter period and this paper examines the performance of the Northern Ireland houses over the months of June, July and August 2016. While this report provides valuable insight into the performance of the house, the strength of the monitoring exercise being carried out by the Ulster University will be further enhanced by analysing the relative performance of the house compared with the other building regulations houses and passive houses being monitored at the same time, both in the Republic of Ireland and in Northern Ireland. This is the subject of a future paper.

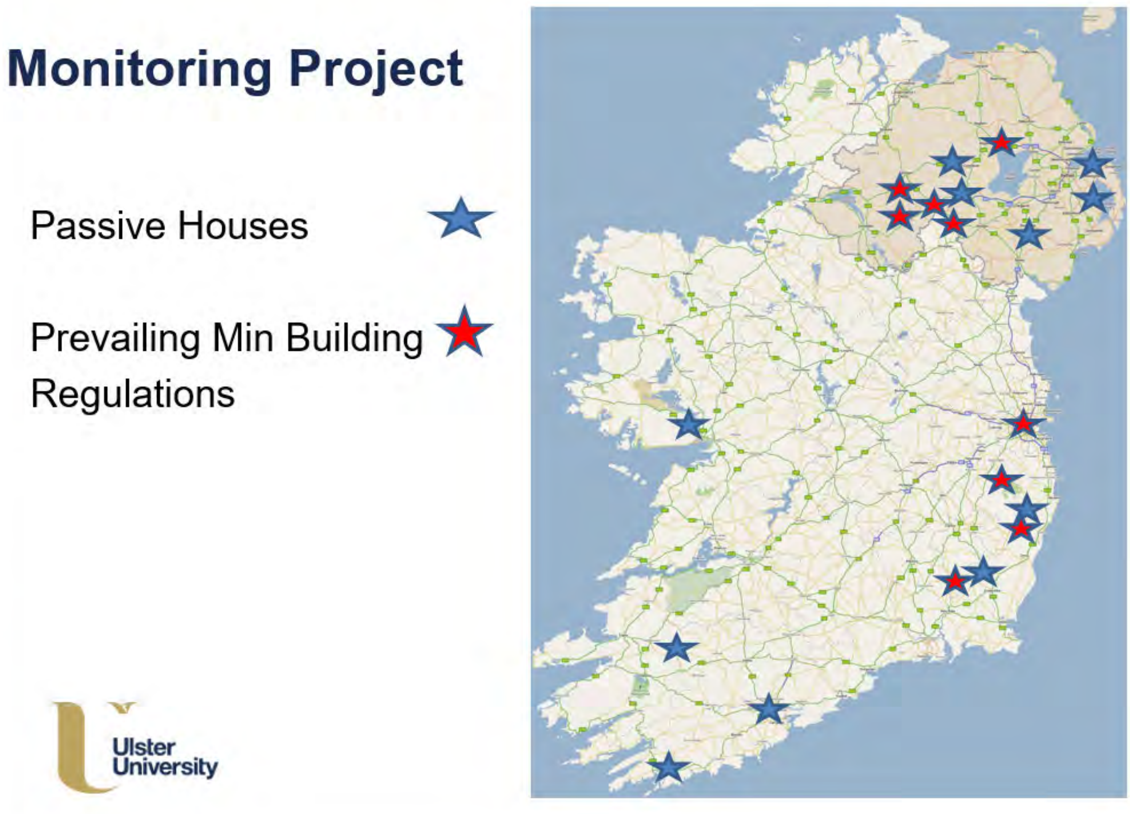

Figure 1 Locations of monitored passive houses and Building Regulations Houses

Table 1 Overview of the Monitored Houses

House	Building Type	Construction	Constructed	Size {m^2}
PH 1	2 storey Hse, Detached	TF	2014	158
PH 2	Bungalow, Detached	TF	2013	220
PH 3	Bungalow, Detached	TF	2011	145
PH 4	Detached	TF	2016	247
PH 5	Under construction	n/a	2017	n/a
BRegs 1	2 storey Hse, Detached	Block	2010	329
BRegs 2	2 story hose, Detached	TF	2014	294
BRegs 3	2 Storey, Detached	Block	2013	230
BRegs 4	2 Storey, Detached	block	2016	210
BRegs 5	2 storey Hse, Detached	Block	2015	246

The following metrics are being gathered at five-minute intervals for the nine houses currently being monitored:

a. occupancy profile

b. indoor air temperature
c. indoor relative humidity
d. indoor carbon dioxide concentrations
e. outdoor temperature
f. outdoor relative humidity
g. wind speed
h. barometric pressure
i. energy consumption

The monitoring unit is a commercially available unit with the following specification:
Temperature (indoor): Ranges from: 0°C to 50°C. Accuracy: ± 0.3°C
Temperature (outdoor): Ranges from: -40°C to 65°C. Accuracy: ± 0.3°C
Humidity (indoor and outdoor): Ranges from: 0 to 100%. Accuracy: ± 3%
CO_2 meter (indoor): Ranges from: 0 to 5000 ppm. Accuracy: ± 50 ppm or ± 5%
Sound meter: Ranges from: 35 dB to 120 dB

Calibration tests have been carried out on the devices and it has been found that some individual units unit did not perform to the stated specification with respect to carbon dioxide concentrations, and also relative humidity. It was found that the RH of a number of the units exhibited an offset (of up to 10%, i.e. instead of reading the correct 70%, the unit records and indicated 80%). For this reason the RH is not discussed in detail in this report. The unit uses an optical CO_2 sensor and automatically re-calibrates at fixed intervals. This calibration is carried out assuming that the minimum CO_2 level reaches 400 ppm. Wide bands for carbon dioxide concentrations have been used to allow for any inaccuracies in CO_2 measurements and follow-on measurements are planned with laboratory grade carbon dioxide sensors. All units have been found to perform within specifications regarding temperature.

Thresholds have been established for the key metrics being monitored and the percentage of time individual metrics exceed the thresholds are considered. Passive Houses are designed to have a uniform set temperature of 20°C throughout. A temperature threshold has therefore been set at 20°C. Thresholds have been defined to reflect the set temperatures in SAP at 21°C for the living room and 18°C for the other parts of the dwelling.

A set temperature of 24°C is required in SAP in the case of air-conditioned buildings, and the final threshold temperature of 25°C reflects the temperature that passive houses are allowed to exceed for no more than 10% of the time.

Results

Despite the small sample size of four passive houses and five building regulations houses, some clear trends are emerging in relation to the interior temperatures experienced in the dwellings. It is noted that summer temperature readings are not available in B Regs 4 and PH 5 and that limited readings are available in PH 5. An analysis has been carried out of the prevailing weather over the monitoring period, and it is noted that the summer of 2016 experienced similar temperatures to 2014 but higher temperatures than 2015 (by 1.1°C on average), but 30% less sunshine than the previous two years.

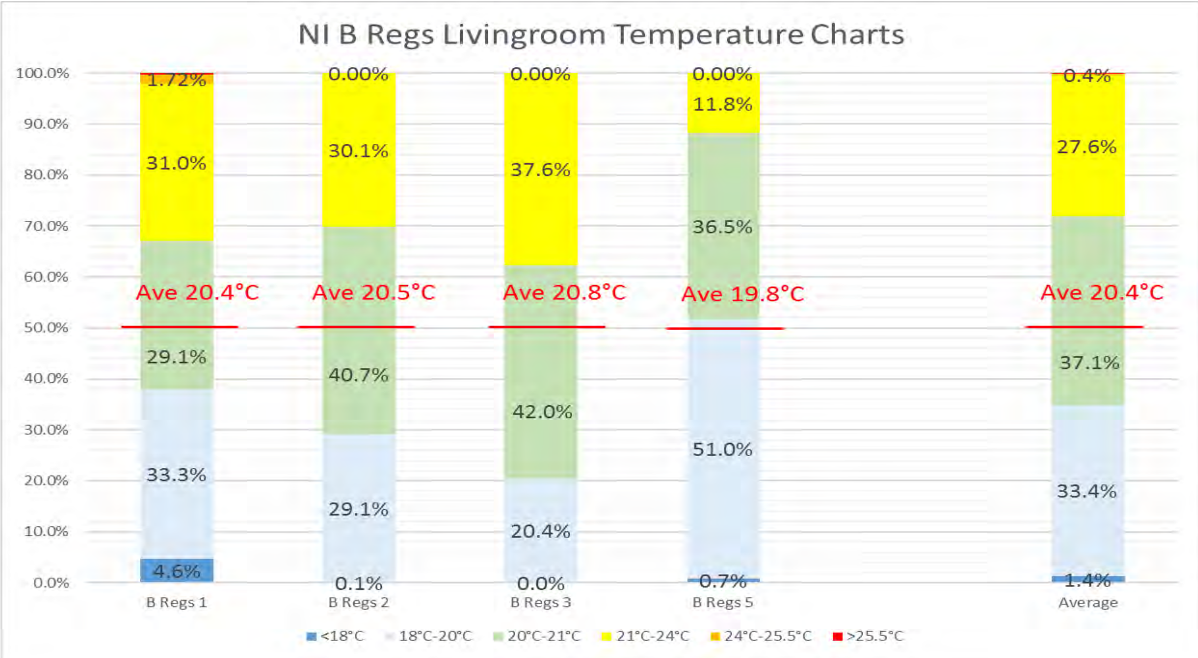

Figure 2 Average building regulations living room temps June, July, August 2016

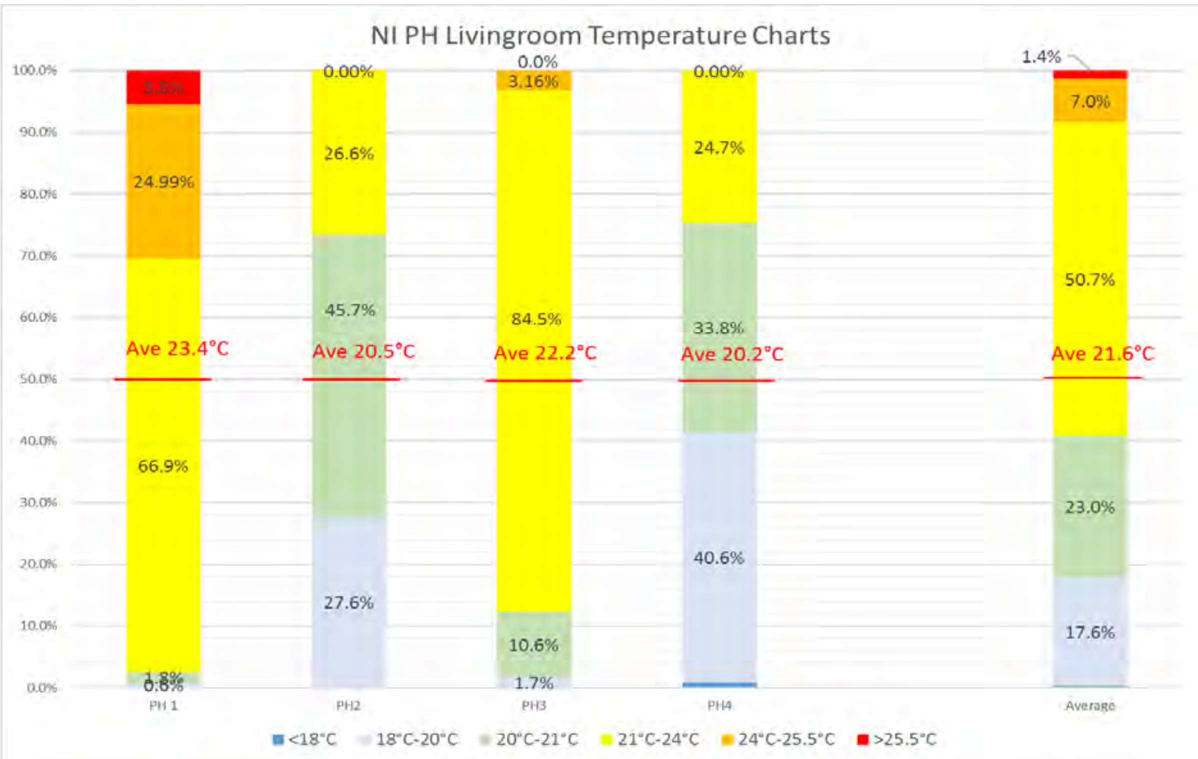

Figure 3 Chart of the NI Passive House living room temps, June July and August 2016

Figures 2, 3, 4 and 5 give the proportion of time that temperatures where experienced in the building regulations and passive houses both individually and as groups over the period broken down into the distinct temperature bands previously defined in addition to the average temperatures.

Living room temperatures

Figures 2 and 3 refer to the living room temperatures. The average temperature in the group of building regulations houses is 20.4°C and that in the Passive House group is 21.6°C. Thus the average summer temperature in the Passive Houses is 1.2°C above that in the buildings complying with the minimum building regulations.

In addition, the living room temperature in the houses complying with the minimum building regulations are at or above the building regulations set temperature of 21°C for 28% of the time, while the average Passive House temperature meets or exceeds the set temperature of 21°C more than twice as frequently at 59% of the time.

Considering the set temperature for passive houses (20°C), the Passive House living rooms on average are seen to meet or exceed this threshold for 82% of the time, while the building regulations houses meet or exceed the temperature threshold for 65% of the time.

Regarding overheating, the average of the building regulations house living room temperatures do not exceed the threshold of 24°C, while the Passive House exceeds the threshold for 8.4% of the time, and exceeds the Passive House threshold of 26°C for 1.4% of the time. While these figures are well within the limit of 26°C for 10% of the year specified by the Passive House Institute the living rooms of the Passive Houses are seen on average to have significantly higher temperatures during the summer period than the houses merely complying with the minimum building regulations.

Considering the individual houses, PH 1 is seen to exhibit the highest temperatures, with temperatures exceeding 25.5°C for 5.5% of the time. A retractable awning was installed over the southerly fenestration in September 2016, to reduce summer overheating.

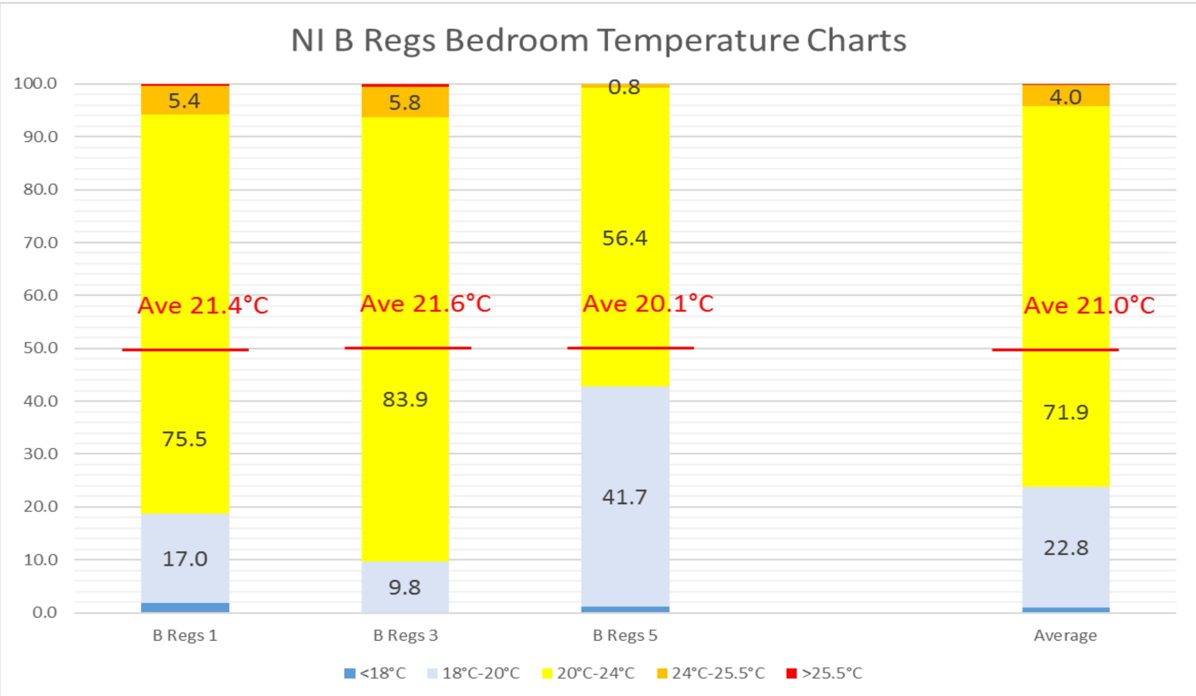

Figure 4 Chart giving the building regulations bedroom temps June, July, August 2016

Bedroom temperatures

Considering figures 4 and 5, it is seen that the trend of higher average temperatures continues in the passive house bedrooms, with the average temperature being 1.5°C higher in the passive houses (22.5°C compared with 21°C). During the summer period the temperature of the bedrooms in the passive houses and houses complying with the minimum building regulations consistently exceed the set temperature of 18°C required by the building regulations. Considering the Passive House standard set temperature of 20°C, the average temperature meets or exceeds this 95% of the time in passive houses and 76% of the time in houses complying with the minimum building regulations.

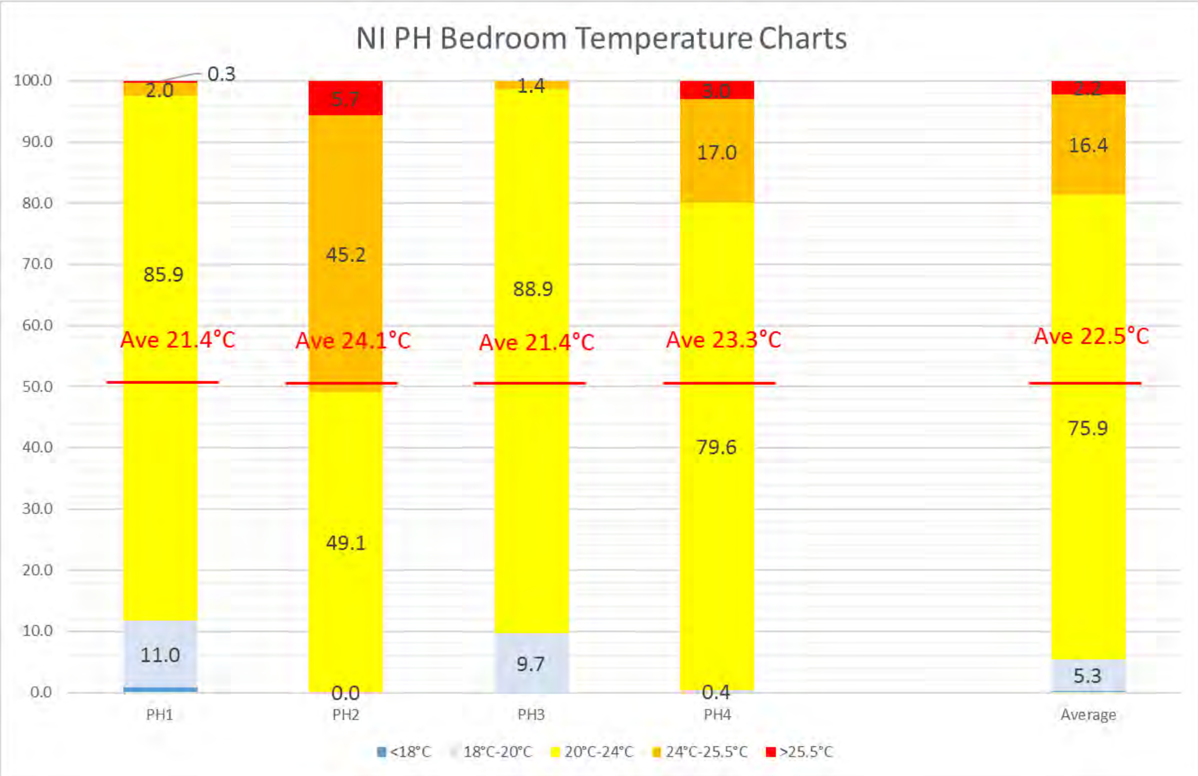

Figure 5 Chart giving the Passive House bedroom temperatures for June, July, August 2016

The temperatures in the Passive House bedrooms exceed the threshold of 24°C 18% of the time, and exceed the threshold of 26°C for 2.2% of the time. This compares with the building regulations bedrooms which exceeding the 24°C threshold only 4% of the time. Some passive houses are thus seen to record considerably higher temperatures than building regulations houses, whilst still operating within the Passive House maximum temperature limit of 26°C. It is noted that B Reg 1 and 2 had higher bedroom temperatures than PH 1 and 3, whilst experiencing slightly higher or similar average temperatures.

PH 2 is seen to exhibit the highest bedroom temperatures. The master bedroom is located on the second floor and opens onto a double height gallery which is directly over the living room. This is seen to contribute significantly to the high temperatures in the bedroom.

Qualitative assessment

In addition to the quantitative assessment reported above, the house owners were interviewed to assess their perception of Indoor Environmental Quality, along with a number of other questions in relation to their use of the property, overall satisfaction with the dwelling, costs and also the general suitability of the passive house standard for more widespread deployment. This information will be presented as part of another paper. Table 2 looks specifically at Indoor Environmental Quality aspect and shows the level of occupant satisfaction based on perceived overheating, stuffiness, dry throat and noise of the mechanical heat recovery and ventilation system, in addition to overall IEQ satisfaction. Scores are rated on a scale of one (best) to 7 (worst).

Table 2 Occupants Satisfaction Levels

House	Overall IEQ Satisfaction	Overheating (Summer)	Stuffy (Winter)	Stuffy (Summer)	Dry Throat?	MVHR Noise
PH 1	1	3	1	3	1	1
PH 2	2	5	1	5	1	1
PH 3	1	2	3	2	1	1
PH 4	2	1	1	2	1	1
B Regs 1	1	2	2	2	1	1
B Regs 2	2	4	2	4	1	n/a

All owners reported some level of lack of satisfaction with high summer temperatures or summer stuffiness. The highest perceived overheating occurred in PH 2, with the owner reporting significant dissatisfaction during the summer with overheating, and a sense of stuffiness. This predominantly related to the night-time bedroom temperatures, which recorded the highest levels of the four passive houses studied, related to the location of the bedroom over the double height living room. In addition, the owner of PH 1 reported summer overheating in relation to bedroom temperatures.

The owner of B Regs 4 also reported significant dissatisfaction with overheating during the summer.

The owner of PH 3 reported more overheating and stuffiness during the winter period with the summer due to issues related to regulating the stove output, and the sometimes large number of visitors. She reported that the temperature was regulated by opening the doors to other rooms.

It is noteworthy that the building regulations house owners also reported summer overheating.

Corbon Dioxide Concentrations

In addition to the findings of higher temperatures in the passive houses, the passive houses were also seen to exhibit more uniform average concentrations of carbon dioxide (619 ppm for the living rooms and 616 ppm for the bedrooms) compared with the houses complying with the minimum building regulations (514 ppm in the living rooms and 820 ppm in the bedroom).

Conclusions

Monitoring has been carried out of four NI passive houses and four “standard” houses (built to the minimum building regulations) over the months of June July and August 2016. Both quantitative and qualitative analysis has been carried out to determine the performance of the two groups of houses.

A key finding is that differences are emerging in terms of the interior temperatures with the group of Passive Houses recording on average a 1.6°C higher temperature in the living rooms and a 1.4°C higher temperature in the bedrooms compared with the building regulations reference houses.

On a quantitative basis neither the houses complying with the minimum building regulations nor the Passive House standard are seen to exhibit significant overheating. The passive houses are seen to experience more frequent breaches of the stipulated Passive House threshold of 26°C. All the passive houses complied with the requirement of not exceeding the 26°C threshold for more than 10% of the time. Despite operating within specifications, the majority of owners of the building regulations houses and passive houses perceived some level of overheating during the summer, and reported difficulty in regulating the temperature by opening the windows given the occasionally high outdoor night-time temperatures.

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Performance analysis of external shading devices: A case study of a typical office building typology in Cape Town, South Africa

Tim Coleridge[1] and Ruxandra Huh[2]

[1] Graduate School of the Environment, Centre for Alternative Technology, Machynlleth, Powys, SY20 9AZ, United Kingdom, tim.coleridge@cat.org.uk
[2] Graduate School of the Environment, Centre for Alternative Technology, Machynlleth, Powys, SY20 9AZ, United Kingdom, ruxandra.huh@gmail.com

Abstract: The building sector accounts for a third of the worldwide energy consumption. With the continuous rise in global temperatures, reducing the cooling loads in buildings is one of the main strategies in mitigating climate change in the built environment. Passive energy efficient design in hot climates can lead to a significant reduction in energy use while promoting occupant comfort. This study analysed the performance of external shading devices applied to a typical office building in the Mediterranean climate of Cape Town, South Africa. Evidence from a critical review of global literature informed the development of a base model and seven shading device typologies. Experimental testing aimed to inform best practice by optimizing the internal daylighting, and reducing the energy consumption. Computer based simulations conducted through Revit and DesignBuilder analysed the daylighting levels, annual cooling demand and peak electricity consumption. The results show that the most efficient passive design features for the selected location are the horizontal louvres, inclined double louvered canopy and surrounding shade. As the climate and sun path in Western South Africa are similar to Central Chile and Southern Australia it could be concluded that the findings are applicable for office buildings in these locations.

Keywords: Shading devices, Low energy, Mediterranean climate, Sustainability, Passive cooling design

Introduction

The building sector accounts for 35% of the overall energy consumption worldwide, out of which commercial buildings are responsible for 55% (Hayter et al, 2000). High glazing use in office building façades necessitates control of solar radiation entering rooms (Carbonari et al, 2001). Furthermore, cooling accounts for 24−38% of the total energy consumption in Mediterranean climates (Kamal, 2010) such as Western South Africa. Passive design in hot climates can lead to a significant reduction in energy use while promoting occupant comfort (Roaf, 2009). These factors informed this study's focus on the commercial sector of the built environment, specifically energy efficient cooling strategies for non-domestic buildings, aiming to make the following contributions to the field:

- to evaluate the principles of passive cooling design in the South African context;
- to address a specific gap identified in the local literature;
- to serve as technical guidance for the construction industry;
- to propose further research and recommendations to be undertaken based on current outcomes.

The main research question is to evaluate the optimal design of external shading devices for non−domestic buildings in Mediterranean climates, using a case study office building design in Cape Town, South Africa as the focus of the research methodology. Evidence from a critical review of current literature, combined with practitioner experience in the field, informed the development of a base model and seven typical shading device typologies: horizontal canopy; inclined louvered canopy; vertical fins; surrounding shade; inclined double louvered canopy; and vertical and horizontal louvres. Experimental testing focused on energy use reductions for cooling, heating and lighting, but view performance was also considered. The main hypothesis is that the implementation of passive cooling strategies can provide improved occupant comfort and reduce energy consumption and CO_2 emissions.

Existing literature regarding the design of shading devices highlighted a number of challenges and solutions that have directly informed the research strategy for this study. Carbonari et al (2001) argued that the most efficient shading devices, including glare control, for the climate and sun path of Italy are the horizontal louvres with 45^o angle inclined slats. Li et al (2007) identified the most efficient length of a horizontal canopy is 0.9m. A key challenge identified by Ahsan (2009) is providing effective shading on the eastern and western facades, due to the low incident sun angles falling on these elevations. Ahsan (2009) argues heat gain can be reduced from these facades by minimizing the window−to−wall ratio or by orientating the longer axis of the buildings along the east−west direction. More recently, Mandalaki et al (2014) concluded the most efficient shading devices in the Mediterranean climate are: full−façade Brise−Soleil, the inclined double canopy, the louvered canopy and the surrounding shade.

The scope of the existing research spans over a variety of locations such as Greece (Mandalaki et al, 2014), Malaysia (Ossen et al, 2005), Bangladesh (Ahsan, 2009), Italy (Carbonari et al, 2001) and Korea (Kim and Kim, 2009). Other researchers, such as Ochoa et al (2012) compared multi−objective optimization criteria for reduced energy use and high visual performance. Frontini et al (2012) have analysed the impact of shading devices on mean radiant temperature in office buildings. Although several studies investigate the performance of shading devices in Mediterranean climates, there is a visible gap in the knowledge of local literature that focuses on the specific sun path of South Africa.

Passive design considerations affecting the study boundaries

Energy efficiency can be achieved either through passive design, such as orientation of the building, choice of materials or use of shading devices, or through active strategies, such as choice of HVAC systems, solar water heaters or rain harvesting systems. Passive design takes advantage of the local climate for maintaining a comfortable indoor temperature and reducing the need for auxiliary heating or cooling (Bellia et al, 2013). Indirect solar gain and thermal mass can contribute towards low- and zero-energy design (Martinez et al, 2012), but these factors have been excluded from the scope of experimental research for this study as typical office buildings in South Africa have a high percentage of glazing. Similarly, whilst high performance glazing can limit solar gain (Frontini et al, 2012), they are not the focus of the current study because high investment costs make these types of glazing configurations atypical. Furthermore the study focuses on fixed external shading devices such as canopies, fins or louvres that hinder the direct solar radiation from reaching the internal space. They are more efficient than internal shading devices such as blinds or curtains which dissipate the heat to the internal air adjacent to the glazing (Datta, 2001).

According to Rosencrantz (2005) both the cooling demand and the annual cooling load could be reduced by half by using external solar shading instead of internal shading devices, leading to 33% reduction in cooling energy use.

Although fixed shading systems have been shown to reduce the cooling load demand during summer, they could also be a source of increased energy use due to possible increased lighting energy and heating demand during the winter months (Mandalaki et al, 2014). Therefore it is necessary to evaluate the heating load reduction and interior luminance with the cooling load reduction. Daylight availability is important not just for physiological and psychological causes, but also for energy saving achieved through an optimal integration between natural and artificial light (Bellia et al, 2013). Research shows that particularly in commercial dwellings, with a high occupancy rate during daytime hours, daylight positively affects workers' satisfaction, performance and productivity (Nazzal, 2005).

South African context

In order to develop passive design strategies for this study it was important to identify the climate and sun path for the investigated location, the energy consumption patterns and sources, and the national standards and policies for the building sector in South Africa. This study looks in particular at the Western Cape Province of South Africa and especially Cape Town – located on the 33.9249°S latitude and 18.4241°E longitude. This coastal location is characterised by Mediterranean climate, with wet winters and hot dry summers.

Sustainable buildings are a necessary construction strategy in South Africa due to limited energy sources and increasing energy demand. South Africa's energy consumption accounts for more than 40% of Africa's total CO_2 emission and almost 2% of global emissions due the heavy reliance on coal for energy production. South Africa, rated as the 15th highest country globally for carbon emissions by the International Energy Agency (2010), has targeted reducing CO_2 emissions to 34% below 2010 levels by 2020 and 42% by 2025. The proportion of dwellings with access to electricity doubled between 1994 and 2003 (Winkler, 2007). Energy supply became too limited in 2011 to satisfy the increased number of residents with access to electricity and the increased life style of the developing country. Major aims for energy efficient buildings in South Africa are therefore both energy demand reduction and decreased CO_2 emissions, which can be coterminous, but not necessarily so (Parkin et al, 2016).

Methodology

In order to identify the optimal shading devices design, the following quantitative and qualitative data gathering strategies were undertaken: 3d modelling of shading devices (using Autodesk Revit Architecture Version 2016, in which typical building materials were assigned) and software simulations (using DesignBuilder, Version 4.7.0.022, in which relevant building and occupant variables were assigned and external shading devices simulated). These methodologies were used due to the integrated capabilities of software engines to perform complex analysis, including energy usage for cooling, heating and lighting, daylighting performance, system loads, temperature distribution and location specific weather data. In contrast to monitored building measurements, software simulations offer the ability to test and compare various shading devices under the same conditions (Maile et al, 2007). DesignBuilder uses Radiance backward ray tracer in order to calculate annual daylight availability – proven more efficient and reliable than split−flux methods used by other competitive programs such as Autodesk Ecotect (Mandalaki et al, 2014). DesignBuilder is also validated under the comparative Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs (ASHRAE, 2005).

Building variables

The modelled building was based on the findings of comparative analysis of typical office building typologies in South Africa. Data collection took into account the top floor of such a typical office building, simplifying the plan layout to an open office area and a central closed core that would include all the circulation components (staircase, elevators etc.) and utilities (plant room, ablutions etc.), as shown in Figure 1 below. All building materials complied with South African National Standard (SANS) 204 for the Western Cape zone.

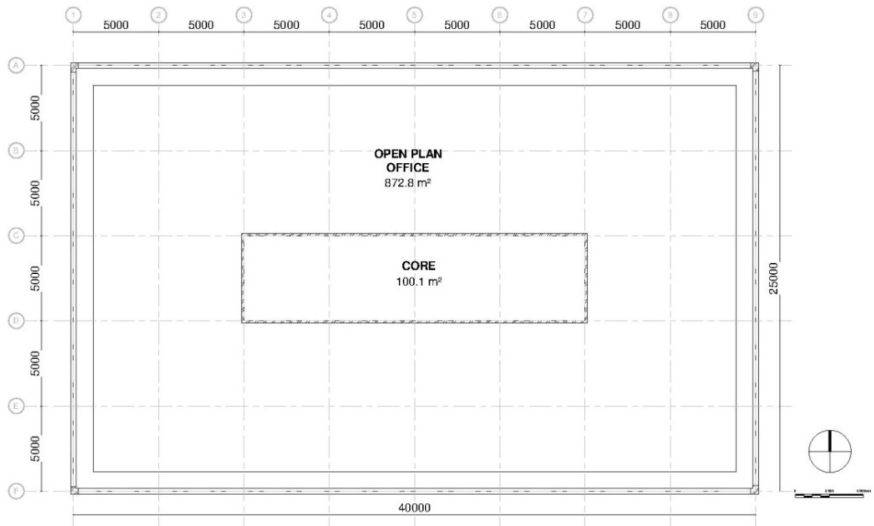

Figure 1. Typical simplified office building floor plan

The 1000m^2 footprint plan (40mx25m) was orientated along the east–west axis, as proposed by SANS 10400 XA, with a floor to ceiling height of 4m, external brick walls, with 2.5m high surrounding curtains walls (cill height at 1m), reinforced concrete surface bed/suspended slab, and a reinforced concrete flat roof. The floor is assumed as adiabatic, being situated above a zone with similar indoor thermal conditions. A wide variety of glazing materials and technologies are used in the industry, but 6mm single pane, clear glazing with a 70% visual transmittance and 10% aluminium frame ratio was chosen as a worst-case scenario permissible under SANS204. The software simulations were analysed comparatively against a base case with no shading, and all scenarios were modelled using the same building materials, so the choice of glazing will have no impact on the performance of the shading devices and the reduction in the energy consumption. All shading devices were modelled as aluminium – a wide spread practice due to the material's high reflectance of light and reduction of unwanted heat gain. Although heat transmittance of the materials is relevant for the annual energy consumption calculation, it will not affect a comparative study with identical conditions.

Occupancy variables and boundary conditions

Given the aim of the research was a comparative analysis of various shading devices, all other simulation variables were kept constant throughout all scenarios. Occupancy data and boundary conditions were very important factors for the reliability of the simulations and were therefore based on real buildings or building standards recommended by SANS. The metabolic rate, density of occupancy, efficiency of HVAC systems and the mechanical ventilation were in accordance with the national standards. The ventilation is completely mechanical, and the fuel used entirely electricity from the grid, as considered typical for an office building in the study context.

Scenarios

The modelled shading devices (shown in Figure 2) were based on an extensive literature review of passive cooling design. The findings from Kim and Kim (2009) have been used for the scenario 2 (horizontal canopy), scenario 3 (inclined louvered canopy) and scenario 6 (inclined double louvered canopy) to inform the optimal depth and angle of the overhangs. Due to a lack of academic literature on vertical fins (scenario 4), surrounding shade (scenario 5), and vertical (scenario 7) and horizontal louvre systems (scenario 8), these shading systems have been based on current architectural practice, comprising examples of external shading devices from a sample of South African commercial buildings.

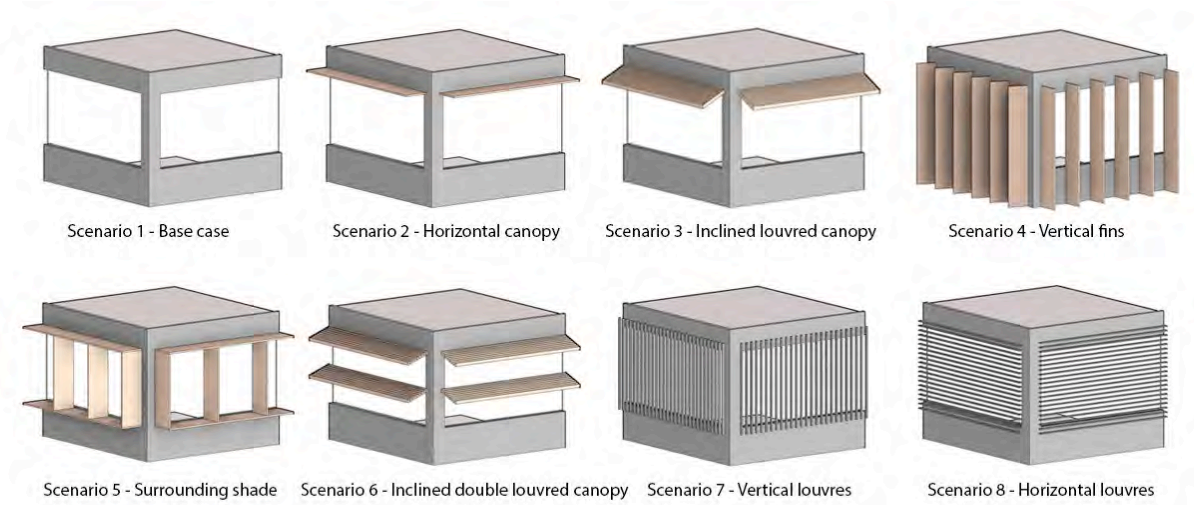

Figure 2. The 8 modelled and simulated scenarios

Simulations started with cooling design calculations undertaken for all scenarios in order to determine the required cooling load needs. Secondly, simulations were tested across an entire year, compiling both annual as well as monthly results, in order to collect the following data for all scenarios: internal gains (monthly and annual), system loads (annual), fuel breakdown (monthly and annual), thermal comfort (monthly) and temperature distribution (annual). Furthermore, daylighting simulation was particularly relevant for the current study as it shows the actual illuminance (lux) for each one of the scenarios. The current study does not take into account the glare which will account for the occupant's comfort ratio. Lastly, the view performance has been assessed by analysing the elevations of the façade from a visual permeability point of view.

Simulation results

The following Figure 3 below presents a summary of the findings, comparing visual permeability, radiant temperature (as a proxy for thermal comfort), daylighting (illuminance) and energy performance. The results show that the annual cooling demand is 74 293kWh for base study, 52 268kWh (30% reduction) for horizontal canopy, 47 973kWh (35% reduction) for inclined louvered canopy, 49 319kWh (33% reduction) for vertical fins, 42

500kWh (42% reduction) for surrounding shade, 36 136kWh (51% reduction) for inclined louvered double canopy, 38 098kWh (48% reduction) for vertical louvres and 39 055kWh (47% reduction) for horizontal louvres. By analysing the values in the graphs below, it can be seen that the latter three shading devices provide the highest energy reduction for cooling.

Shading device	Visual permea-bility	Radiant temperature (°C)	Daylighting (lux)	Annual cooling dem-and (kWh)	Peak elect-ricity cons-umption (kWh)	Solar gains exterior windows (kWh)
1. No shading	100%	20,25-27,89	218-4372	74293	16 000	185 080
2.Horizontal canopy	100%	19,71-26,50	155-2392	52268 (30% reducti-on)	13900 (13% redu-ction)	128 040 (30% reduc-tion)
3. Inclined louvred canopy	85%	19,36-26,18	136-2418	47973 (35% reduction)	13750 (14% redu-ction)	111 620 (39% reduc-tion)
4. Vertical fins	95%	19,32-26,91	90-1892	49319 (33% reduction)	14000 (12% redu-ction)	105 890 (42% reduc-tion)
5.Surrounding shade	97%	18,96-25,97	82-1534	42500 (42% reduction)	13100 (18% redu-ction)	85 057 (54% reduc-tion)
6. Inclined double canopy	70%	18,28-25,31	89-803	36136 (51% reduction)	12600 (21% redu-ction)	65 834 (64% redu-ction)
7. Vertical louvres	55%	19,50-26,20	6-314	38098 (48% reduction)	12 500 (21% redu-ction)	48 079 (74% redu-ction)
8.Horizontal louvres	60%	18,85-25,64	92-731	39055 (47% reduction)	12500 (21% redu-ction)	74 539 (60% redu-ction)

Figure 3. Summary of findings for the 8 simulated scenarios

The lowest electricity consumption is in June for the base case but in September for the rest of the buildings with shading devices. The peak electricity demand is in January, with a value of 16 000kWh for the base case, 13 900kWh (13% reduction) for the horizontal canopy, 13 750kWh (14% reduction) for the inclined louvered canopy, 14 000kWh (12% reduction) for the vertical fins, 13 100kWh (18% reduction) for the surrounding shade, 12 600kWh (21% reduction) for the inclined louvered double canopy, 12 500kWh (21% reduction) for the vertical louvres and 12 500kWh (21% reduction) for the horizontal louvres. The best performing shading devices for peak electricity consumption are the same as those for the annual overview of the energy demand.

Regarding the view performance the horizontal canopy provides significantly lower daylighting levels of 155lux to 2392lux with a 4m deep perimeter of 800lux−1700lux. This is also consequently high for a workplace. Therefore this shading device might need to be coupled with internal blinds or venetian blinds that can be manually or automatically adjusted according to the solar or heat gain. The third simulated scenario of inclined louvered canopy has similar daylighting levels of 136lux−2418lux. Furthermore tilting the slats by 20o would provide an equal distribution of light to the rear space through the reflection of the sunrays and bouncing on the white surface of a ceiling. The vertical fins provide a further decrease of light levels to 90lux−1892lux, with a perimeter of 600lux−1400lux. The surrounding shade provides similar daylighting levels of 82lux−1534lux, with a shallower perimeter zone of approx. 3m. Both the horizontal louvres as well as the inclined double canopy provide daylighting of approx. 90lux−750lux, with a perimeter of 300lux to 600lux, which is almost ideal for a workspace. The overlit zones are shown as spots, which could be individually analysed and corrected. The internal space around the utilities core provides a lux of under 250lux, which could be increased by the use of additional lighting or the design of the circulation around these zones. The vertical louvres provide the lowest but most uniform daylighting levels of 6lux to 314lux, which would require a very intensive use of artificial lighting.

The study aimed to gain an initial understanding of how a selection of external shading devices affects energy consumption and occupant comfort, which involved an overview of a range of typologies and characteristics rather than an in depth optimisation study. The software selected for the simulations had limitations that meant it was not possible to quantitatively test certain aspects of the scenarios' performance, such as effects of glare from the external shading devices on the occupant comfort and perceived radiant temperature across the floor plans. Further limitations of the study comprised not investigating the effects of building materials in detail, the depth of the shading devices and angles of the louvres on each of the particular orientations. Whether comparison measurements such as daylighting, fabric gains and radiant temperatures reflect the actual occupants' comfort in the current context is an ongoing research question. The model equations for simple geometrical configurations of shading devices have a degree of inaccuracy compared to real market products. Therefore, for more complicated geometrical models and orientation types (such as northwest facing facades) other types of research are required. The paper provides fresh empirical understanding of a sample of shading typologies typically used in practice in the study context, and hence passive cooling strategies, but it is acknowledged that each individual architectural project will have particular demands and solutions based on their specific context and occupants' needs.

Conclusion

The present research has shown to support the identified hypothesis that by implementing passive cooling design strategies it is possible to reduce the cooling demand of the typical office buildings studied in Cape Town, South Africa and thus reduce the total energy consumption and CO_2 emissions and enhance the internal comfort that would benefit the health, well−being and productivity of the occupants. The primary aims that were achieved are: identifying principles of passive cooling techniques, providing an overview of South African regulations and future targets, providing a technical guidance for the construction industry, filling in a gap in the local academic literature, proposing further research to be undertaken based on the current findings.

As the solar path is dependent on the latitude of the countries, when designing a shading device, it is necessary to refer to a specific location (Corrado et al, 2004). The Mediterranean climate can be found in: California, Central Chile, Mediterranean Basin, Western Cape of South Africa and Western and South Australia. Most of the countries in the specific climate zone have a wide range of sun angles, except Central Chile, Western South Africa and Southern Australia. The implication of this finding is the applicability of the current research not only for Western South Africa but also for Central Chile and Southern Australia. The next emerging question seeks to overcome the barriers of implementing the design features in practice. It is relevant at this point to have an overview at the triggers and trends in the sustainable building sector. As perceived high initial costs is one of the biggest hindrance to the adoption of energy efficient features (Dodge Data and Analytics, 2016), it should be understood that both the architects and consultants, as well as the developers, owners and tenants, play important roles in achieving sustainable buildings.

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Design to Thrive

Validation of Wladimiro Acosta´s Helios System

Florencia Collo[1] and Simos Yannas[1]

[1] Architectural Association, School of Architecture, London, United Kingdom

Abstract: Wladimiro Acosta s architectural practice shows him to have been a pioneer of passive design back in 1930, but his work is little known and has remained unstudied by the environmental research community. His approach to designing with climate is described in his book "Dwelling and the City" published in 1936. It introduces Acosta's "Helios System", a design method for architectural solar control that precedes Olgyay's by some 20 years. It allows designers to size vertical and horizontal building elements providing solar protection in combination with design strategies for window sizing and operability. The paper presents a critical review of Acosta's system using current computational tools to assess his solar control devices for two buildings he designed in Buenos Aires. Computer models were assessed by hourly simulations of incident solar radiation on windows and sun penetration indoors. The results are compared to Acosta's original criteria and designs. The analysis shows that the principles established by Acosta are still valid for Buenos Aires. His climatic assessment was accurate and informative. The Helios System is well-founded and compares with the tools we have today. On close examination Acosta's designs are well informed.

Keywords: Wladimiro Acosta, Helios System, Solar Control, Environmental pioneer

Introduction

Wladimiro Acosta was a pioneer in the use of meteorological science for architectural purposes. He was a Russian architect who emigrated to Argentina in 1920's. At his arrival, modern architecture was starting to spread in Latin America. He valued the functionality and scientific approach of modernity, but was critical of replicating it without local adequacy. Instead, he analysed vernacular architecture of Buenos Aires –old colonial buildings- as examples of efficiency and comfort. He considered that to do a proper design he needed to "study the physical and human geography of the place, its characteristics, its technology, its construction techniques, the indigenous ways of living, and find an architecture that belongs to the place." He did research on solar studies, Buenos Aires climate, and the incipient comfort theories which he used to inform his practice. Acosta's approach to designing with climate is described in his book "Dwelling and the City" (1936). It introduces his "Helios System", a design method for architectural solar control that precedes Victor and Aladar Olgyays' "Solar Control and Shading Devices" by some 20 years.

The climate

Buenos Aires 's climate, according to the Koppen-Geiger classification is temperate or sub-tropical, moist all seasons (average ranges from 43 to 91%) with mild winters, and hot summers. The annual average temperature is of 17.6^{o}C, with predominant winds coming from N, NE, and E. Over the warm period, cloud coverage is low, whereas in the cold period days are mostly cloudy. Rainfall is fairly distributed along the year with a mean possibility of 30%.

Methodology

Both Acosta's theory and application will be reviewed in this paper. His principles will be offset by contemporary authors, whereas his application will be tested through simulations comparing his intentions with actual performance. Solar radiation, shadow masks, and shadow studies were conducted using Ladybug for Grasshopper.

Fundamentals of the Helios System: the scientific approach

Climate and comfort research

Acosta used historical weather data supplied by the Direction of Meteorology. In his essay Urban Climate (Acosta, 1936), he details the concept of the Urban Heat Island in Buenos Aires. His findings were supported by studies performed by Goldmerstein and Stodieck (Acosta, 1936), with similar concepts as the ones explained by Gartland in Heat Islands (Gartland, 2008). This phenomenon was confirmed locally by Figuerola-Mazzeo only in 1997. Also, Acosta points out the necessity to account for trees and green spaces inside the city to mitigate UHI, later confirmed by the LA studies of Akbari (2001). He based his design consideration on his notion of thermal comfort which included air and radiant temperature, humidity and air movement, introducing a topic that Fanger developed only 34 year later (Fanger, 1970). Also, he was well aware of the notion of comfort band and the scarcity of means to quantify it there were at that time. He followed the state-of-the-art of the studies performed by several scientists of the epoch (Acosta).

Acosta´s thorough studies of climate, its influence on the city and architecture, and consequently on human comfort prove that his vision of the topic was not only accurate but also well ahead of his time as it compares to the contemporary approach of environmental design.

Solar studies

Acosta acknowledges the sun as the main source of energy, and solar studies as a starting point to initiate a building design. With the geographical positioning of Buenos Aires (34° South), he derived the most relevant solar angles that would inform his architecture (Figure 1). Also, he tempted to create a way to represent them in 2d, preceding Hand's charts (1948) mentioned by Olgyay by some 16 years.

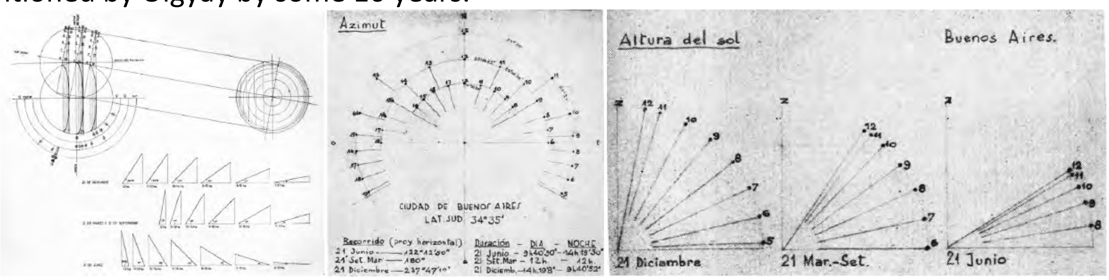

Figure 1. Solar angles' studies (source: La Arquitectura Helios, Acosta)

For Acosta knowing accurately the path of the sun was essential to deciding on the orientation of a building. He advanced many effects of the contemporary building physics such as solar radiation, radiant temperature, and heat transfer. He evaluates solar contribution for the climate of Buenos Aires as "detrimental during summer, since it adds to the hot atmosphere, and beneficial during winter, because it can compensate the cold from the exterior", demonstrating a perfect understanding of the physical implications. Recognising the importance of solar control, and knowing the right angles at a set time of the year, Acosta investigated several systems of regulation depicted in Figure 2a, before reaching the optimal which he called the Helios System (Figure 2b). Also, he used solar angles to test his designs (Figure 2c) and show the operation of the system, preceding Olgyay's "Solar Control & Shading Devices" by some 30 years. Acosta understood the relevance of solar control, studied it scientifically and made it the leitmotif of his architectural practice.

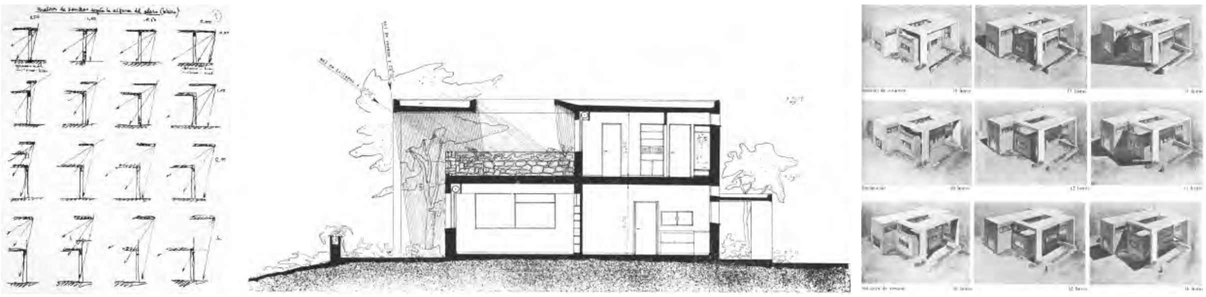

Figure 2. Solar studies on architecture (source: Vivienda y Clima, 1936)

The scientific approach to design is completed with the post occupancies studies he did, taking photographs of the buildings after completion to confirm his theory, verify sun angles and building use at different times of the day and year (Figure 5). He used these images as a way of explaining his work.

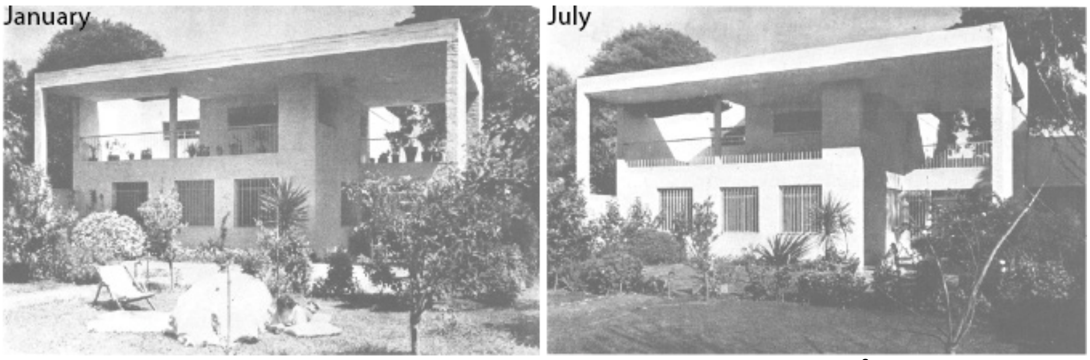

Figure 3. Documentation of built work (source: Nuestra Arquitectura n° 202, 1946)

Helios System

The main points of the system are summarised in Figure 4.

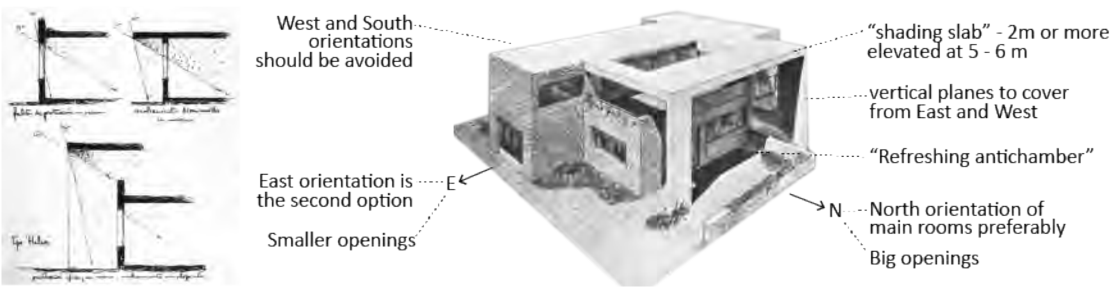

Figure 4. Helios System (source: Nuestra Arquitectura n°168)

The starting point is the orientation of the building for which the decision is subject to solar access, breeze capture, and moisture regulation. He recognises North as the most advantageous orientation for its solar properties, and the predominance of NE winds in Buenos Aires. Following, he marks a difference between East and West. East receives breeze and morning sun, which he considers "excellent in winter and bearable in summer". However, West orientation should be avoided as it "receives afternoon sun when the atmosphere is already hot" (Acosta, 1936). Acosta realises that although the amount of incident radiation is even, the earlier exposure weighs for East. Regarding moisture, he mentions North orientation is still the most advantageous because high levels of humidity can be dried by the sun.

The fixed shading devices, which he calls “shading slab” are the most recognisable feature of the system. The best solution is to protect both walls and windows already north oriented with a “combination of large projecting slabs of 2m or more, elevated at a double height of 4,50 to 6m, and vertical protections N-S oriented”. This creates a “refreshing antechamber”: a transitional space used as protected entrance, shading device and as an element for architectural composition. A shading mask was performed (Figure 4b) overlapped with the overheated period, considered when the monthly mean temperature is higher than the lower comfort limit (Szokolay, 1996). If the room is facing due north, the system entirely covers the overheated period, and lets the sun in the entire winter. However, if the facade starts to deviate (Figure 4c), the overhang lets the sun in near midday and covers either early in the morning or late in the afternoon during winter. For the system to work, the maximum acceptable deviation from due north is 20°.

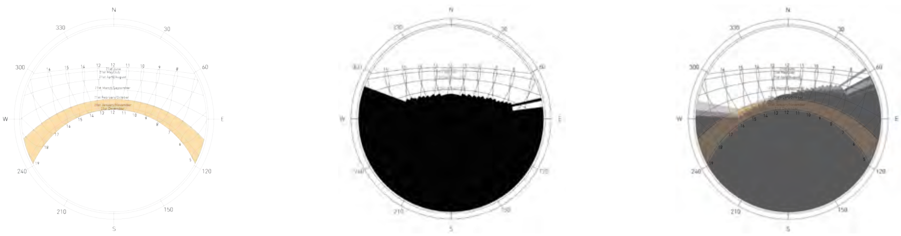

Figure 5. Helios System shading masks

With reference to the openings, Acosta points out the necessity of adjusting the size according to orientation for the purpose of solar control, maximising openings to the north and minimising them to the south and west. Also, he acknowledges that different shapes and positions can modify daylight distribution, and points out that the higher the window, the further the light enters the room. Finally, suggests that all the windows should have an operable upper part for ventilation purposes.

With regards to adapting to a denser urban situation, where orientation is conditioned by narrow plots, Acosta states that solutions are reduced beforehand, and that the architect can only “remedy the adverse circumstances”. Therefore, the system is intended to relatively open areas where choice can be made, and does not specify how to deal with more unfavourable conditions.

Acosta put the well-being of the users at the centre of his design procedure, considering all the aspects to establish a design methodology for Buenos Aires. His theory compares with the contemporary approach of environmental design.

System’s application: 2 case studies

The design and direct application of the system will be reviewed in this section in two case studies: a detached house, and a high-rise building. Solar control will be assessed by the system’s capacity to limit solar loads and to protect against direct irradiation (Kuhn, 2000).

Case study 1: Helios House in Villa del Parque

This is a detached house on a large plot with very few constraints to design with. The proposal is fully designed according to environmental principles.

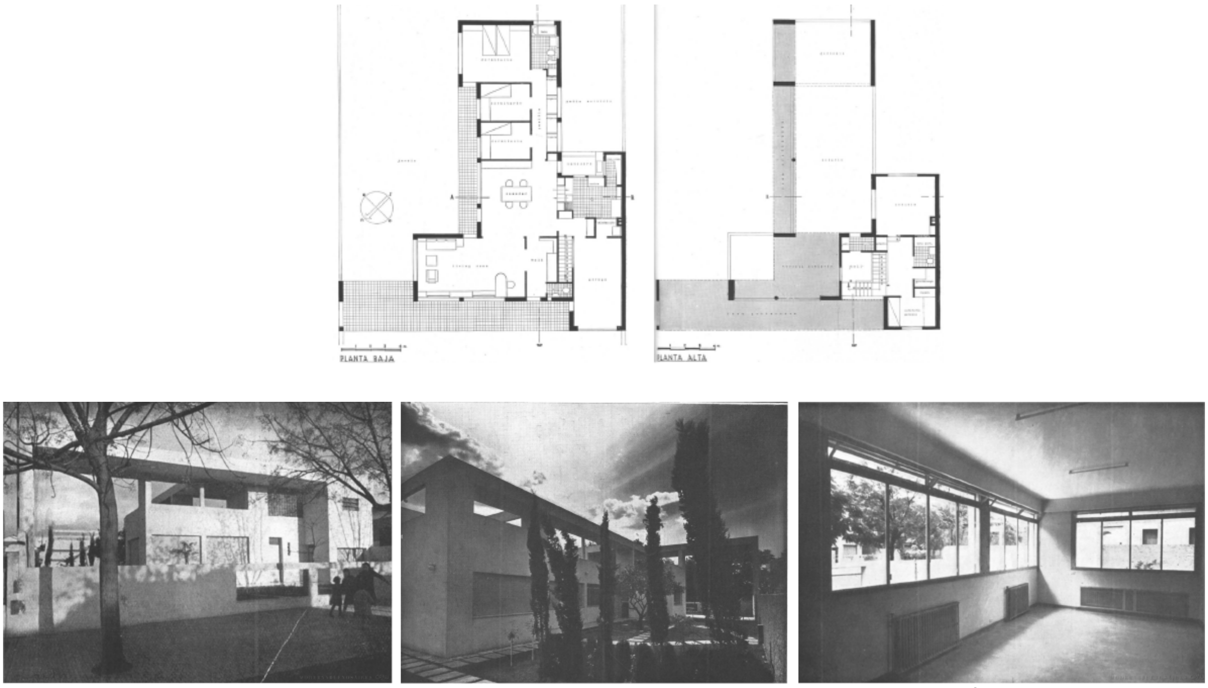

Figure 6. Helios House in Villa del Parque (source: Nuestra Arquitectura n°122)

The overall layout is clearly designed to optimise interior comfort. The main functions are located on the ground floor, where temperature is more stable and the system of overhangs is intended to work, leaving service functions -atelier, service room, gymnasium- on the top floor (Figure 6). Bedrooms, dining room and living room are NE oriented, which Acosta considered optimal, with big windows overlooking the garden. Special attention is given to the solar control of the windows, as the main feature of the Helios System. Overhangs –"shading slab"- are a fixed component, dimensioned to guarantee protection and allowance of the sun when needed. Also, there is a range of adaptive opportunities provided: night shutters, interior curtains, and an operable upper part for ventilation. Kitchen, garage, toilets and storage are SW oriented, with small unprotected windows, only intended for daylight and ventilation purposes with their corresponding mechanisms. However, the living room is facing both NE and NW, with windows on both sides.

summer solstice
equinox
winter solstice

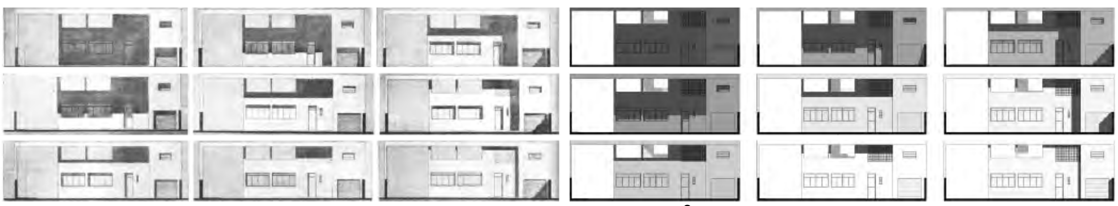

Figure 7. Shadow studies by Acosta (source: Nuestra Arquitectura n°122) and contemporary simulations

Figure 8. Pictures by Acosta of sun movement in 1939 (source: Nuestra Arquitectura n°122)

Acosta performed shadow studies as a design tool (Figure 7a) and as a post occupancy study. Both the simulations (Figure 7b) and the pictures he took prove that he could exactly predict the position of the sun at a set hour and design with this input in order to regulate the indoor thermal environment. Even if the size of the overhangs varies for the NE and NW orientations, they remain insufficient to serve the front facade. The architect foresaw this deficiency and offset it with tree shadow (Figure 8).

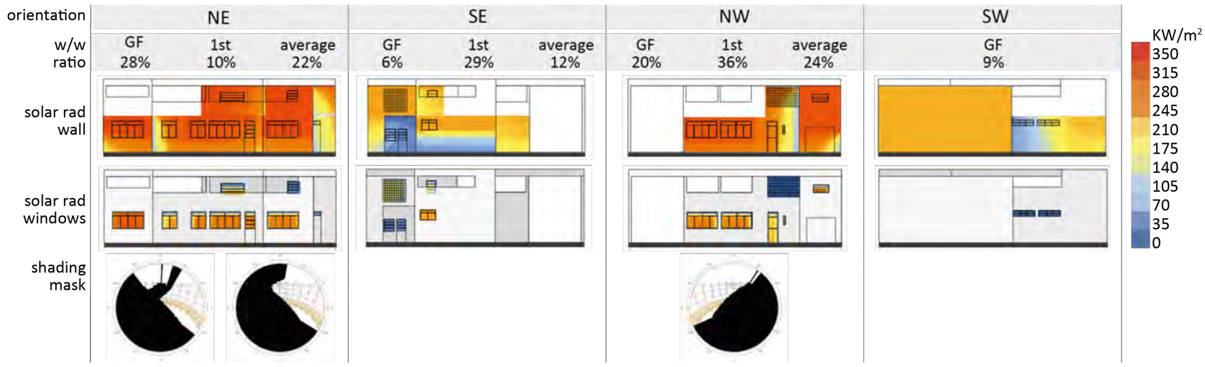

Figure 9. Validation of the solar control of the Helios House in Villa del Parque

As predicted in the previous section, the deviation from due north is greater than 20%, and the shading device leaves an excessive period of overheated hours unprotected. The front facade -NW- lets the sun in all the afternoon during the whole year. Regarding the solar load, results confirm that all the facades remain exposed and the shading system does not reduce significantly the quantity of solar radiation hitting the windows -from 320 to 280 KWh/m^2 , as an average- .

The disposition of the rooms in plan and section, size of openings, adaptive opportunities, and shading are planned in line with solar principles, which is remarkably advanced for the time. Nevertheless, the system of overhangs is applied here as if the orientation was due north, causing to reduce the performance. Acosta fully understood the fundamentals but did not adapt them properly for this orientation.

Case study 2: Rent House in Palermo Chico

This rent house was the only high rise building Acosta completed (1943). The plot was surrounded by large parks that have remained until today, with high potential for views. The typical plan is asymmetrical, T shaped, covering less than 2/3 of the plot.

The entire design optimises conditions for the comfort of the users. The main rooms -living and bedrooms- are located facing NE with very big windows (72% w/w) and very large balconies (2.2m). Maximum adaptive opportunities are provided, having guaranteed the performance with the use of the fixed balcony – “shading slab”-. Rooms are naturally ventilated through sliding panels and an operable upper part in all the openings. Bedrooms are provided with night shutters, and living rooms with a system of operable venetian blinds. Acosta took care of every mean for the users to regulate their thermal environment. He made such an emphasis on these devices that he showed special detailed pictures of them in publications (Figure 10).

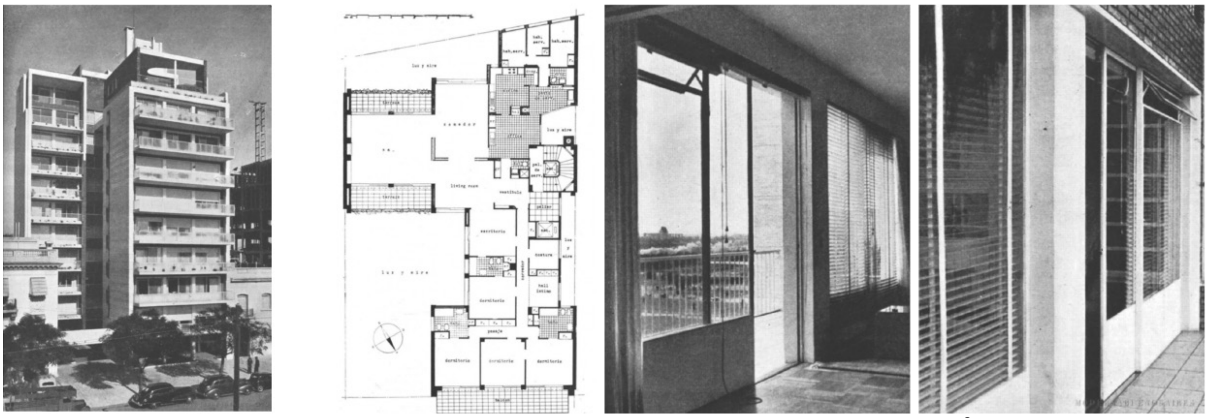

Figure 10. Rent house in Palermo Chico (source: Nuestra Arquitectura n°168)

Secondary rooms are facing SE and located in the centre, protected through the rest of the rooms. All the service functions of the dwelling are located facing SW and NW and sheltering the main rooms from the afternoon sun.

Acosta mentions that if the neighbour construction is built on the whole party wall, it would be a “hygienic and economic catastrophe since the air-and-light yards would become holes, and the rooms would not have any sun nor light”.

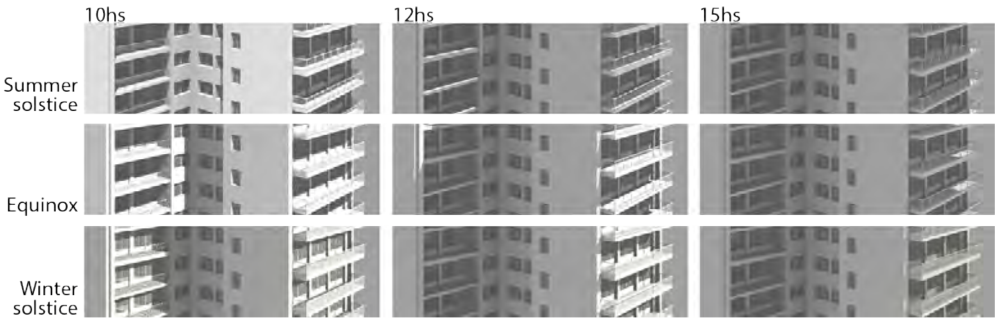

Figure 11. Shadow studies

Shadow studies (Figure 11) prove that the size of the balcony is perfectly calibrated. During the warm period, the sun barely reaches the balcony at all times and spares the window completely, preventing the interior from overheating. During the cold period, the sun reaches both the balcony and the interior, acting as a source of heat gain. At the equinox, the run rays reach the balcony, but not the glazing area, preventing the interior from excessive gains, but creating an enjoyable outdoor space. Results from the solar load analysis (Figure 12) confirm the adequacy of the overhangs for its significant contribution to reducing the amount of solar radiation: from 280 to 80 KWh/m^2. It is to be noted that SW orientation has larger windows than expected -56% w/w-, to enable views to the park.

Figure 12. Solar control assessment

Discussion

Although Acosta's studies of the vernacular architecture of Buenos Aires are highly relevant to learn from its considerations, his most meaningful contribution was to approach climate as a scientific tool that could inform his designs. He developed his theory in the 30's, which is still factual today. All his meteorological studies are useful, and briefly explained to reach a wide audience. The solar studies he carried out are also valid today. The principles of the Helios System for Buenos Aires are accurate and suited as guidelines. Furthermore, the identification of a system of shading devices as the key element design in the mentioned climate is instrumental as a starting point. Both case studies confirm that the application of the system was precise, and encompassing all the aspects of environmental design as we understand it nowadays. However, Acosta utilised the scheme that was intended for due North in rotated angles, as for the Helios House in Villa del Parque, which weakened the performance of the entire system. Comparing the two cases, the high-rise building shows a better performance than the detached house due to a lower deviation angle from due North. The guidelines Acosta provides are most relevant when choice can be made, but fails to explain how to cope with other situations.

Conclusion

Wladimiro Acosta was a pioneer in addressing environmental design scientifically, as he understood all the topics we cover today through the latest scientific research of his time. It is very likely that he was the first to use meteorological science as a mean to inform architecture. The Helios System is well-founded and seems to be a reasonable starting point to design in Buenos Aires, highlighting solar control with overhangs. His suggestions may be of a reduced application in today's urban context, though his thorough studies and principles are still solid and will remain a valid reference for Argentinian architects.

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The 6*Zs* Refugee Shelter

Marwa Dabaieh[1]

[1] Department of Urban studies, Malmö University, Sweden.
marwa.dabaieh@mah.se

Abstract: Various natural and man-made disasters force the affected population to flee from their homes to other safe places. Providing these affected people with quick and cost-efficient shelters is always a challenge. Recently, issues regarding the supply of energy to refugee camps have been a main concern given the crises of displaced populations and the problem of how to supply energy to the camps. This study has the purpose of discussing the design of an eco-cycle refugee emergency shelter with the aim to reach a six '*Z*' target (i.e. '6*Zs*'), meaning zero emissions, zero energy, zero waste, zero cost, zero indoor air pollutants and zero impact on the environment after the shelter demolition. The key idea of this eco-cycle shelter is to reach a net 6*Zs* during all stages: material extraction, building construction, operation and maintenance until the shelter's end of life, which depends on plant-based row materials are brought in from the surrounding area to the building site. The study will discuss the design concepts involved and draw conclusions on the feasibility of achieving the 6*Zs* target through the modelling and simulation of the shelter's energy consumption, thermal performance and net carbon emissions. The beneficiaries of this project include not only refugees but also the majority of the world's urban poor. The shelter is designed for the cold Swedish climate, but the method can be adjusted to other climates or geographical contexts.

Keywords: Zero emission, Refugee shelter, Plant-based construction, Eco-cycle design

Introduction

Forced migration is not a new phenomenon. Throughout time, human beings have moved from one place to another to escape poverty, conflict or environmental dilapidation (Castles et al., 2014). During 2015–2016, Sweden experienced a strong wave of refugees from Syria as asylum-seekers due their circumstances of civil war and conflict. Sweden initially had an open-door policy, which put pressure on various Swedish institutions to act accordingly and quickly accommodate thousands of refugees. Sweden welcomed more than 160,000 asylum-seekers in 2015, with nearly 40,000 arriving in October alone. For a country of fewer than 10 million, this was equal to a population gain of almost two percent in one year. Setting up temporary camp hostels was one quick solution to house both families and individuals for several months, and in many cases, the refugees ended up staying there for two years until they were relocated once again in temporary housing. During this time in temporary housing, refugees suffered from difficulties like accessing washing and cooking facilities, as these are shared with others. In addition to privacy concerns, gender separation caused much inconvenience and tension inside the refugee camps.

Normally, temporary refugee housing is built to last one or two decades at the most, but sometimes, they are demolished after only two or three years. However, even during such a short lifetime, each housing unit utilises a wide range of resources in an energy-intensive construction and building process – from raw material extraction and production to construction and operation all the way to the end of the shelter life and consequent disposal. In addition, despite this short life span, the impacts of operations like annual heating and cooling energy as well as maintenance have a significant economic cost and environmental impact. In-depth studies are needed to assess the impact of such temporary structures and determine how their environmental burden can be lessened. The destruction of the refugees' previous houses during war and the effects of destructive weapons have taken their toll. This inspired the main concept of this project in November 2016 with the notion to design a low-cost and low-impact refugee shelter that could also be built quickly. This study discusses a design proposal for a 37m² eco-cycle refugee shelter from plant-based and earth materials. It aims at reaching six 'zero' (6*Zs*) goals: zero energy, zero emissions, zero waste, zero cost, zero indoor air pollutants and zero impact on the environment after the shelter's end of life. The methodology followed in this project is an experimental, participatory action research for designing and constructing a physical prototype as proof of concept in a living lab environment. In this paper, the design intentions and the theoretical notions for achieving the 6*Zs* concepts assessed by simulation verification will be discussed. In later stages of this project, more detailed calculations and numerical analyses will also be conducted followed by a proof of concept of the full-scale model. The project will be located in Brunnshög, Lund, which is in the Scania region of southern Sweden (Skåne), and the area acted as a test bed for the proof of concept of the physical model.

Literature review

There are few assessments of the impact of humanitarian shelters and construction especially in regard to emissions and their carbon footprint. Moreover, in the discourse, limited research tackles the issue of energy efficiency and thermal comfort for emergency shelters. Kuittinen and Winter (2015) show in their study that construction materials have a major impact on the carbon footprint of humanitarian temporary shelters. From the sample shelters they researched, they found that the shelters made from bio-natural materials are those with the least impact compared to others made from industrial materials (i.e. metal-intensive structures). In another study, Cornaro et al. (2015) analysed the thermal performance of tents equipped with photovoltaic systems in two different Italian climatic contexts. Their study showed a decrease in energy demand for heating of almost half and improved indoor comfort conditions in summer without the need for mechanical cooling. Here, they mainly used aerogel pads as high-insulation material in an easy retrofit solution to the original design of the tents.

Recently, other researchers have also started looking at the lifecycle energy and cost analysis for temporary, post-disaster housing. Atmaca and Atmaca (2016) compared the impact and cost efficiency of both prefabricated and temporary container housing in the Turkish context. Their study revealed that prefabricated housing is better in terms of cost and energy consumption over a 15-year period. This falls in line with the same outcome in the study by Islam et al. (2016) which calculated the carbon footprint lifecycle environmental impacts of shipping containers in Australia. This showed that the operation phase has the greatest impact. This later study can inform other research work in regard to using shipping containers as temporary shelters given their abundance and the fact that they have a lifetime of up to 60 years.

Applying passive solutions to humanitarian shelters is always one of the biggest challenges in a cold climate. A building simulation study by Crawford et al. (2005) evaluated the thermal behaviour of humanitarian shelters in cold climates with the goal of delivering design solutions and materials for quick and low cost deployment. In their study, many factors were considered, but the most important were moisture content and vapour production. They simulated two models in three different cold climates using calibrated data from environmental chamber tests. The study results showed that it is not feasible in all cold climates to depend solely on solar passive heat gains to attain the optimal indoor climate. Yu et al. (2016) constructed three bamboo-wood test cell models and monitored their thermal performance in a lab environment for the cold, Chinese climate. They tested different roof coverings and thermal insulation materials, and the results were compared to the data from monitoring being carried out on existing bamboo-wood shelters in Lushan, China. They also came up with different scenarios for combining low-cost thermal insulation materials with low-tech and affordable roof structures that can resist wind in winter and allow ventilation in summer. One of their suggestions was to use polypropylene sheets for walls, cardboard and air-bubble polythene sheets for roof thermal insulation, and fiberglass cement as a roof covering. Manfield (2000) compared some vernacular solutions and purpose-built shelters for cold climate practice, looking at several criteria like cost, weight, packing volume, delivery time, and most important, the thermal comfort. He suggested in his work that a tent environment that depends solely on casual gains from occupants could eliminate the need for fuel-burning stoves for heating. While other research was mainly focusing on acclimatization measure for temporary refugee tents and how to enhance indoor thermal comfort using inspiration from traditional Bedouin tents (Dabaieh and Borham, 2015).

In regard to energy supply, Lehne et al. (2016) concluded from their investigative research on energy access in refugee camps that 7 million displaced people in camps have access to electricity for only less than four hours a day. They showed with economical calculations that improved stoves for cooking and solar lamps could save $303 million a year in fuel costs. They highlighted that the issue of energy is an important concern and a crucial challenge to be solved within the humanitarian field. Dabaieh, (2016) suggested a plus energy refugee earthen prototype using solar and wind energy for self-sufficient energy supply. More studies are still needed in the area of energy efficiency and energy performance for refugee shelters. This present study attempts to add to the pool of existing literature by adding more applications for design prototypes with minimal impact on the environment, especially in terms of energy consumption and a comfortable indoor climate for the occupants.

Methodology

Eco-cycle design proposal

The shelter eco-design concept was based on in-depth interviews with 50 refugees based on stratified sampling in seven different camps located in the Scania region of Sweden. These interviews were conducted to learn more about the refugees' needs, the challenges they face in their temporary refugee camps in Sweden, and their future aspirations. The refugees were consulted for their opinion of the shelter design, and their comments were integrated in the design development proposal. This step took place in parallel with a literature study and technical meetings. The literature search was meant to look at similar research work investigating the environmental impacts, thermal performance, and cost efficiency of temporary refugee shelters for cold climates in particular. The technical meetings with researchers, architects, engineers and planners, both as individuals and companies (working with eco-cycle, passive, pre-fabricated home concepts) were meant to discuss the feasibility of the design proposal and have an estimated figure for the cost in the Swedish market based on the suggested site for construction. All of these aspects informed the final design proposal to achieve the 6*Zs* target.

Building Simulation for the 6Zs target

The 6*Zs* ideas were then simulated using DesignBuilder software. All the six zero targets were designed from a cradle-to-cradle perspective, from the material production to the building construction until operation and maintenance, and lastly, the demolition state after the shelter's end of life. Several parametric modifications were made for the passive design solutions to reach passive house premium standards as a benchmark. The outcome from the simulation is analysed to evaluate the performance of the passive solutions proposed, in particular, regarding passive heating and daylight as the main challenges in Sweden. Due to the limited size of this paper, only the final outcome of the simulation is discussed.

Results and discussion

The project design concept

The key idea of this eco-cycle shelter is to reach a net zero level of emissions, waste and energy during material extraction, building construction, operation and after end of life. The main wall skeleton is an earth-mix recipe together with reeds and straw. The earthen construction technique is based on the nature and properties of the local building site soil, so that no additives are imported from outside the building site except lime to be used for walls plastering. The Scania region is known to have good soil that is suitable for earth-building techniques and abundance of reeds and straw. It is a known fact that the earth gives off no harmful emissions, and it can be used again as soil or for rebuilding another house, as no chemicals or industrial materials are involved (Snell and Callahan, 2009). According to (King, 1996), earth buildings can last for over 90 years if properly built and according to Jones, (2015) straw bale houses can last for 200 years. The straw and reeds are natural, plant-based materials and used to enhance the earth mix's tensile strength. Both materials are also agents for absorbing CO_2. The plants absorb CO_2 during their growth process, and this continues when mixed with wet clay and decomposed partially into cellulose, which acts as a binding agent. The lime takes in CO_2 during treatment throughout the construction process and building operation with the increase in the indoor air humidity.

Regarding structural aspects, especially the straw bale and rammed-earth techniques, they are both stable for bearing wall structure systems. A standard 40cm-thick, rammed-earth walls can be used for load-bearing in buildings up to four stories high (Boltshauser and Rauch, 2011). Earth is non-flammable, so walls made of earth have the added advantage of being fireproof. The straw and reeds are used as infill for the rammed-earth structure. Also, a traditional final layer of plaster consisting of casein, beeswax and linseed oil is used to protect the facades from rain. Lime is also added to the walls' and roof's external plastering, as a water-resistant agent, in particular, in the erosion lines earth mix of the rammed earth exterior walls. The roof will be made of locally available wood, straw and reed boards and the built-in furniture (bed, sofa and wall cabins) is made from rammed earth and reeds, which will also help reduce the final building costs. In addition, the building can be extended easily if the need arises, and the size can be adjusted according to the number of occupants.

Figure 1 shows the shelter design concept as an outcome of the design meetings with the refugees. Several other technical installations, such as a natural earth refrigerator (8 degrees), so the occupants can store their food for daily use with zero energy consumption in addition to a waterless and manually driven washing machine. PV LED lamps will be installed and other installations will be chosen based on their energy efficiency. A green roof will be used to reduce water runoff, heat loss during the winter and heat gain during the summer from the roof surface. All the technical solutions shown are the outcome of the focus group technical meetings.

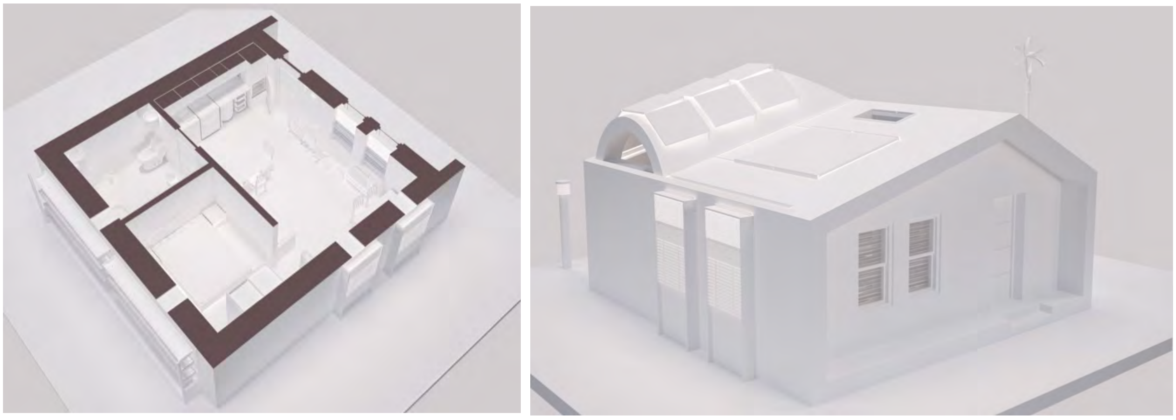

Figure 1. The concept for the refugee shelter, to the left is the 3D model showing the passive and the renewable active systems used and to the right is the plan showing the shelter zones.

eco-cycle design application towards the 6Zs goals

The goal of *net zero carbon* is achieved through using plant-based building materials (straw, reed and wood) through low-tech production and construction with a short transportation distance from building site. Using a green wall and a green roof act as carbon offset to achieve the net carbon target. The electricity is produced using renewable resources; however, the embodied carbon in the PV and wind turbines production is outside the boundaries of this study. The total carbon emissions calculation from manufacturing, construction, operation and demolition of the shelter was 0.02 kg CO2 e/m3.

The goal of *net zero energy* is attained through using hybrid renewable energy systems (Solar PV and Wind) shown in figure 2 for renewable energy production with an extra energy surplus to be utilised for other purposes like charging stations for e-bikes and e-cars or for street lighting. The preliminary simulation results for the shelter's yearly energy performance showed a total annual consumption of 28 kWh/m² and energy production is calculated to be round 120 kWh/m² year. These results were only for electrical appliances, night lighting, and heating during approximately seven weeks in winter. Passive heating and cooling solutions like Trombe wall and earth pipes are used to reduce the heating and cooling loads thus reducing the overall energy consumption of the building. The energy needed for cooking is mainly fuelled by bio-gas produced from household and neighbouring farm lands organic waste.

Net zero cost will be achieved through using renewable sources for electricity production calculated for a short payback during the shelter's complete lifetime of 15 years. The extra surplus of energy to be produced and sold to the neighbouring greenhouse which during the 15-year lifetime will cover the other building material and construction costs. The labour cost is also waved because the refugees will build the houses themselves. They will be paid incentives as motivation for their participation. Net zero waste is an important goal as the waste products will be either reused or recycled. The organic waste from the kitchen and the faeces from separating toilets will be used as bio-gas for the cooking stove. The urine will be used as fertilizers for the green wall and green roof. The grey water will be used for irrigation. The entire house structure will go back to soil after end of life or can be recycled again as building materials such as compressed earth blocks. Figure 2 shows the waste and water cycle.

Zero indoor air pollutants will be achieved through using plants like English ivy, Boston fern, snake plant and others as a natural air filtering solutions. They absorb chemicals and particles in the air and purify the indoor air. Some plants even produce O_2 during the night, and that will reduce the CO_2 concentration during sleeping periods. Figure 4 and 5 shows the integration of air purifying plants in the Trombe wall and green wall systems. A zero impact on the environment is yet another important goal. The main construction materials are natural, plant-based materials and can be recycled again or go back to nature as compost or soil. Earth, wood, reeds and straw constructions are not only environmentally friendly, but also represent a return to nature after the building end of life or demolition.

As for the thermal performance, the simulation found that the highest indoor temperature during summer was 23.5°C and the lowest in the winter was 14.5°C. In regard to humidity, the preliminary simulation showed that the annual maximum was 74.3%, and the minimum was 43.8%. Passive concepts in heating, cooling and daylighting are the key design aspects that reduce energy consumption during the building operation. These passive solutions include the earth pipes, a high thermal mass double wall, window-to-wall ratio, orientation, shading, Trombe wall, green wall and the cool roof. In order to decrease the dependency on artificial light during cloudy winter days, light shelves were used to reflect daylight into the shelter's interior. Figures 4,5 and 6 show the Trombe wall, green wall, and the earth pipes' passive solutions.

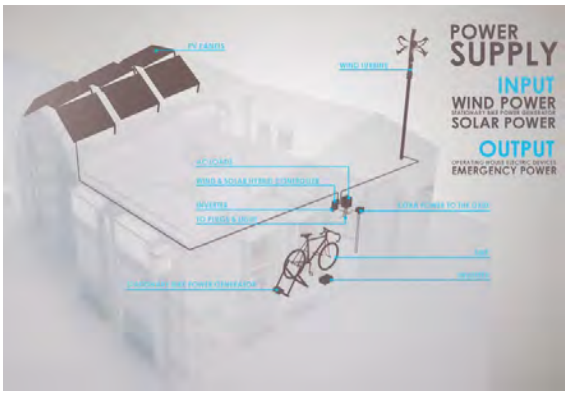

Figure 2. The plus energy concept using a hybrid system of solar and wind power.

Figure 3. The eco-cycle home concept aims to close the loop to reach a zero-waste outcome.

Figure 4. The green wall concept for urban farming, air filtering and passive heating.

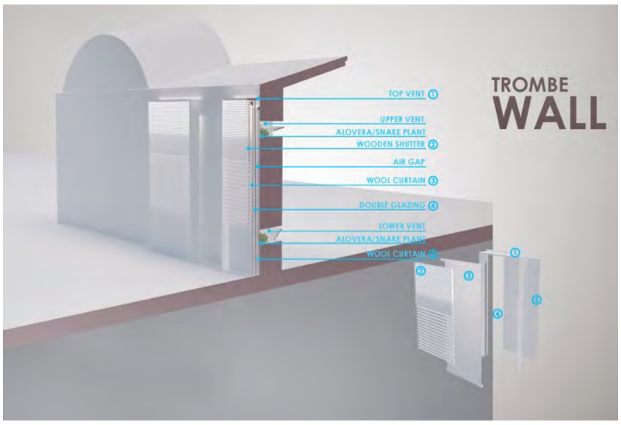

Figure 5. The Trombe wall as a passive heating and cooling system with imbedded air filtering system.

Figure 6. Air cycle system and the earth pipes.

Conclusion

This paper discusses the theoretical background along with the design concept and expected performance of an eco-cycle refugee shelter by using building simulation. Refugee families or even individuals usually have a limited, low income and a lack of resources, and thus, they depend on support. By applying this project prototype, they will not need to worry about the high cost of energy in Sweden. As the proposed prototype is virtually independent of fossil sources of energy and is fully supplied with renewable energy, the low energy requirement for the operation is sufficient to provide a constant supply of energy all year long, even during overcast and muggy days. Living in a shelter house that has a minimal carbon footprint can bring about other changes in the refugees' lifestyle that also have a positive impact on the environment, including growing their own food. In addition, raising children in a passive and low carbon house will also bring about positive change for the next generation whose lives are expected to improve even more. The holistic idea of this shelter design notion is to benefit from living in a passive, zero energy and zero carbon house which also provides high levels of overall comfort without compromising the environment and with a lower cost of living than conventional houses. All results obtained from the simulation were based on the assumption that the passive solutions are utilised at the correct time of the day and night in different seasons. Therefore, training should be conducted as a pre-occupancy strategy and monitoring will be made during the post-occupancy period. More accurate results and testing for the feasibility of this project will be retrieved during the test-cell proof of concept phase.

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Design to Thrive

Climatic comfort in outdoor spaces and its effect on residential complex in the hot and humid climate, case study bushehr, iran

Mahboubeh Engali Dehnavi [1], Mansoureh Tahbaz [2]

[1] Faculty of Architecture and Urban Planning, Shahid Beheshti University, Tehran, Iran,mahboubeh.dehnavi@yahoo.com
[2] Faculty of Architecture and Urban Planning, Shahid Beheshti University, Tehran, Iran,shtahbaz@yahoo.com

Abstract: Architects are seeking the best climatic condition in their designs nowadays. To achieve this goal, the open spaces around buildings as the primary factor in thermal condition, must be considered. The design of open spaces, affects inside thermal comfort and furthermore encourages residents to use open and public spaces. The aim of this article is creating a proper microclimate for the hot and humid city of Bushehr by some thermal outdoor indexes such as humidity, temperature, sun radiation , wind and analysing them by WBGT (Wet bulb global temperature) and TSI (Tropical summer index) index. In the following section, by studying the historic fabric of the city, main criteria related to climatic design is identified. Finally, designing a residential complex in the city of Bushehr is provided based on two criteria: first the climatic condition in the microclimate level and second the historic fabric of the city. Increasing shadows and wind as the main climatic modification obtained from the study have been applied in the proposed design aiming at thermal comfort in open spaces.

Keywords: thermal comfort, outdoor space, residential complex, WBGT, TSI, microclimate.

Introduction

Because of the constant presence of people in residential complexes, climatic design and construction of them is important. Thermal comfort of complexes are affected by climatic conditions of the surrounding open spaces. Thermal comfort in open spaces and creating a suitable microclimate depends on many factors. Climatic parameters such as the wind, solar radiation, temperature, and humidity will effect on the form, shape, and height of the buildings and spacing between them. The shade amount, a limited sky view angle and human factors such as activity, clothing and adapting to climate are other important aspects.

Because of its proximity to the Persian Gulf, low elevation above sea level and low latitude, the city of Bushehr has a hot and humid climate. In this study by analyzing climatic data in one hand and historic fabric of Bushehr (as a valuable pattern of climatic architecture) in the other hand, some principles for designing a residential complex are achieved.

Bushehr Climate data analysis

Bushehr city with Geographic Coordinates Latitude 28° 91’ N, 50° 83' E and 18 meters Elevation above sea level is located along the north coastal region of Persian Gulf in south west of Iran with warm semi-arid climate. The data of the Bushehr weather station during 1985-2005 is being considered for analysing the climate of the city. Temperature, humidity, wind and radiation are the main factors among these data for our analysis.

The Ave. lowest and Ave. highest annual temperature are 11 ° C in December and 38 ° C in August respectively. The Maximum summer temperature during the day is 35.8 ° C and during night is 30.2° C. Two months of the year the temperature is below 18°C, and in the half of the year it's greater than 21°C that crosses from comfort range (18-21°C). Considering Relative humidity comfort range (30%-60%) at 6 o'clock in two months and at 12 o'clock throughout the year, it has a sultry (www.bushehrmet.ir).

Wet Bulb Globe Temperature (WBGT)

The prominent and well-known heat stress index, The Wet Bulb Globe Temperature (WBGT) (ISO 7243, 1982) is a function of important environmental factors in hot condition: air temperature, radiant temperature, and air humidity. WBGT is adjusted for usual work uniform of long-sleeved shirt and pants with and without solar load (Tahbaz, 2011). According to Temperature and humidity data of each month, the following results is obtained. (Figure 2: right), (table1)

Tropical Summer Index (TSI)

TSI is appropriate for hot-dry and warm humid conditions (Sharma, 1986) when the radiant flux is not excessively high, and the subjects have sufficient air motion for any visible perspiration to evaporate off (Tahbaz, 2011).Results obtained from this indicator are shown in (Figure 2: left) and (table 2). Environmental stipulations of TSI are taken by people fully acclimatized, over a duration of consecutive summer seasons (Sharma, 1986).

The results of the data analysis of the weather station and climate indices reveal that Bushehr has relatively short and slightly cold winters and very long and hot summers. As a conclusion, utilizing air flows and shadow to avoid direct radiation, play the main role to create a suitable microclimate in outdoor and indoor spaces. According to TSI Chart that is provided for local people show that for people who are adapted to this climate, critical situation does not exist and better thermal conditions in hot months will be provided with proper design.

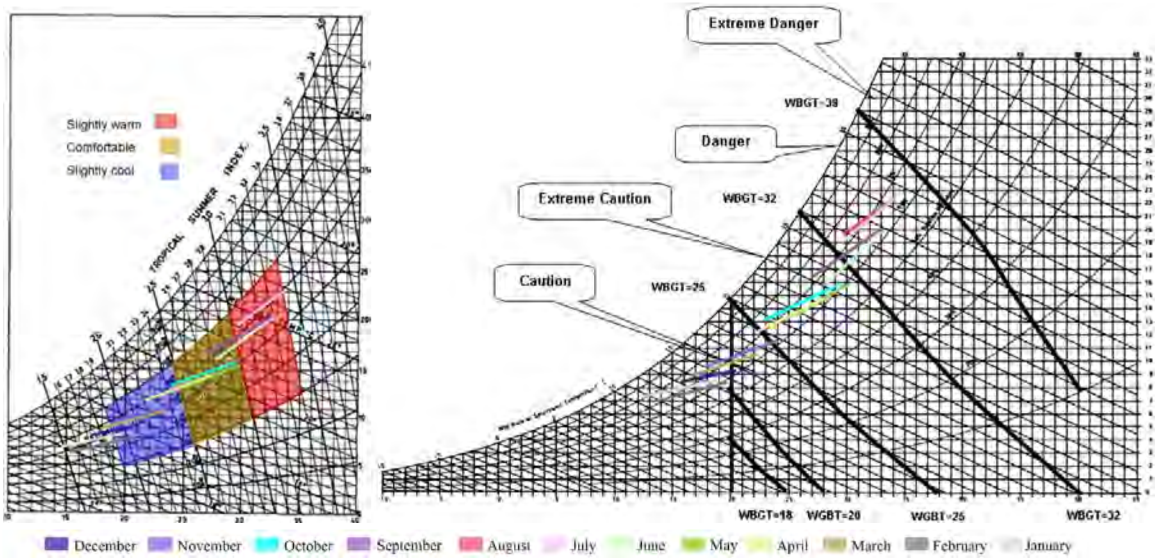

Figure 1: right. WBGT index on psychometric chart using data from the weather station of Bushehr.
Figure 2: left. TSI index on psychometric chart using data from the weather station of Bushehr.

Table 1. WBGT index of Bushehr obtained from psychometric chart.

	WBGT
Late November ,December ,January ,February and March early	20-25° C (caution)
late March, April, May, June early, late September, October early, November early	25-32° C (extreme caution)
Late June, July, August, September early	32-39 ° C (danger)
-	Above40°C(extremedanger)

Table 2. TSI index of Bushehr obtained from psychometric chart.

	TSI
November December January February March	19-25° C (slightly cool)
April ,May, June early, late September, October	25-30° C (Comfortable)
Late June, July August , September early	30-34° C (slightly warm)

Analysis of wind data

In Bushehr as a Peninsula, winds often blow from the sea. According to the wind chart of Bushehr (Figure 2), the prevailing and strongest wind blows from the North West mostly in the afternoon. In the warmest months - July, August, September- wind blow from the West, North West and South West which can be used to create efficient airflow.

Figure 2.Windrose diagram of Bushehr. (www.bushehrmet.ir presented by a local software).

The wind flow in passages

The wind flow condition plays a key role in urban designing, and its climate changes. Designing urban elements such as street orientation, height, and density of the buildings, change wind speed significantly. Urban wind conditions on the street level have a direct effect on human thermal comfort, energy consumption, heating, and cooling (Ranbar et al, 2010). When Distance between the buildings is high, airflows behind of buildings will not effect on one another but in compact construction, formed secondary flows causes turbulence that is essential in Hot and humid climate (Dekay et al, 2013).

Solar radiation and its control methods

Radiation in the form of solar and environmental radiation is another influencing climatic Phenomenon on human comfort (Razjooyan, 2010). The Sunshine duration is one of the factors affect solar radiation .In Bushehr, the least and highest amount of sunshine hours are 61.64% and 82.85%. It's over 60% in cold seasons and 70% in warm seasons.

There is two main controlling factors of radiation at a surface: 1-the amount of solar radiations received at the surface 2-the area on the object subjected to the sunshine. The received radiation at the surface explore in three poses. First, flat areas, second, built areas with low-density, third-built areas with high-density. In the flat ground, reflected solar radiation from the Earth's surface after absorption return to the sky with a long wavelength. In built areas with low-density, the major part of the reflected radiation impacts other buildings and absorb near the surface of the ground (Besharati zadeh, 2011). Figure3

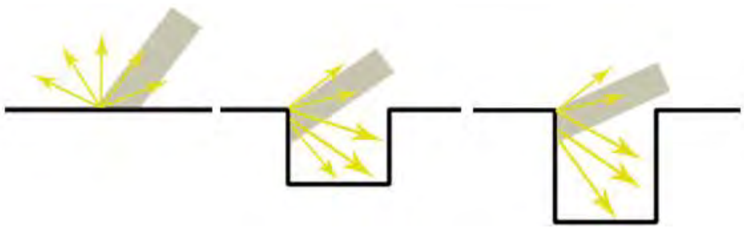

Figure3. Change of closeness and its effect on the sun reflection)Givoni,1998).

To adjust sunlight or shaded areas and surfaces, architects are able to control the sky view factor(SVF) by using settlement regulation such as mass and space and height of the buildings, passage orientation, perspective and proportion (Tahbaz, 2013). Using heat sink materials such as vegetation, water, wood and so on is another solution to decrease surface temperature of the environment (Besharati zadeh, 2011). In Bushehr to decrease the environment temperature it is common to use prominent and adjunct heat sink materials such as wood (shanashir) in the façade of the buildings.

The historic fabric of Bushehr

in The historic fabric of Bushehr, Courtyards in combination with open spaces have formed a balanced combination of mass and space. Passages, lead the wind into the fabric, and open spaces distribute the wind. For achieving maximum wind flow, building blocks as a single or multi-houses are surrounded by intersecting passages. The most important factor in shaping the street network is the wind direction that is affected by sea location in bushehr, By choosing suitable aspect ratios ,passages stay in the shade most hours of the day (Ranjbar et al, 2010). Many crossings passages with open spaces provide the maximum exchange between the building and wind. Main passages are built toward the seaside to take the maximum wind (Figure4). Passages are constructed narrow with an aspect ration of 1/2 to 1/6 width to height for creating more shadow and improving ventilation (Figure5). Edge of the buildings does not comply with the passages, and in the second floor, have over hangs like shanashil to increase the wind flow into indoor spaces (Nikghadam, 2012).

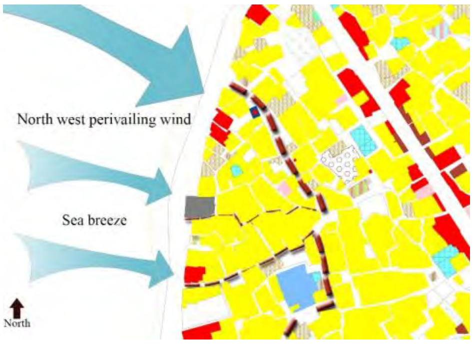

Figure 4. building and passage's orientation with considering the wind direction

Figure 5. An instance of the historical fabric's alleys

Design recommendation

By analyzing climatic data and study of historic fabric, certain criteria defines for thermal comfort design. In this part, some recommendation for the designing and choosing the orientation of passages, buildings, and their placement by considering the wind direction and producing shaded area is specified. Increasing the wind flow, and shaded area, are the main realized criteria in hot and humid climate.

Wind flow

Designed passages to the prevailing wind directions, increase wind flow in the city. For this goal, directions of boulevards and main streets can take 20 to 30 degrees deviation to the prevailing summer winds direction (Dekay et al, 2013). Figure6

To decrease wind shadow in the leeward areas the constructed buildings have porous texture. this placement, helps adjacent building's ventilation. Also, the air in porous fabricate flows through the buildings (Dekay et al, 2013). Figure7

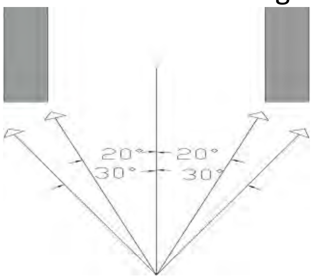

Figure 6. Orientated pathway from the Wind direction.

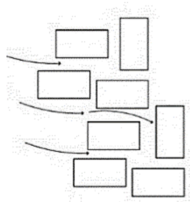

Figure 7. Creation porous texture

Shadows

Buildings can be made in such a way to create overshadow on the adjacent outside spaces and each other (Dekay et al, 2013). Figure8.

The temperature and heat absorbed from the shaded side of a building is low. With less heat radiation in shaded streets in hot climate, the thermal comfort of the pedestrians in open spaces would be improved. Sheltered walk ways and other types of the canopy can be used in the east-west streets which normally take a small shadow (Dekay et al, 2013). Figure9, 11, 12

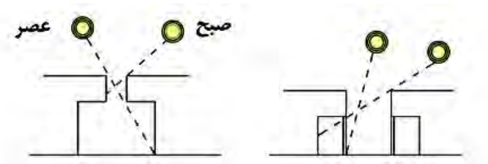

Figure 8. creating overshadow)Besharati Zadeh 2011).

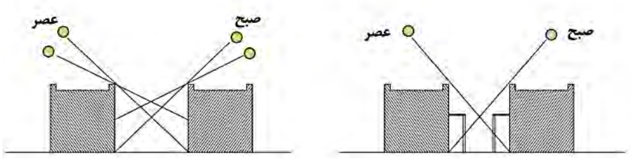

Figure 9.passage with horizontal awning and without awning.

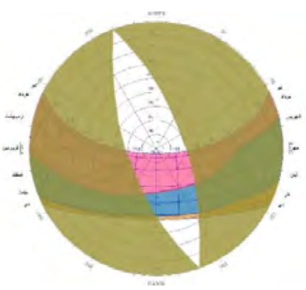

Figure 10.shadow mask for building with Awning

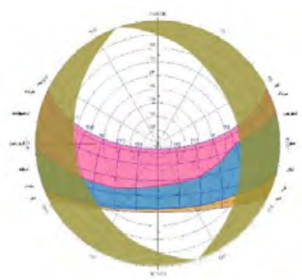

Figure 11.shadow mask for building without Awning

***Vegetation*:**

Vegetation reduces the temperature of adjacent air and surface by 6 to 8 °C due to a combination of evaporation, reflection and shading. Vegetation in dense urban areas creates a local air circulation. The warm air of this area rises and cool air substitutes by reduced pressure on the ground surface (Dekay et al, 2013).

In hot and humid climate shading of trees decrease the radiation flux and as a result the globe temperature (Dekay et al, 2013).

A strip surrounded by low-density trees act as a source of cool air (Dekay et al, 2013).

Proposal design of a residential complex:

The site of the project is located on the east side of Bushehr to design a residential complex for 250 houses (Figure12). Weather factors affecting the site are the prevailing wind from the West North and sea breeze from the beach. In this project, 20 to 30 degrees deviation of passages direction from the prevailing wind direction increases the wind flow. Turning to the South East in this climate reduces radiant heat on the building's wall (Figure13). The blocks Placement by considering design solutions shown in (Figure14). Using central courtyard, creating porous and dense texture, shading for buildings, changing passage's orientation, using covered walkways and vegetation to create the wind flow and shading for complex design are shown in figures15-19.

Figure 12-Site location.

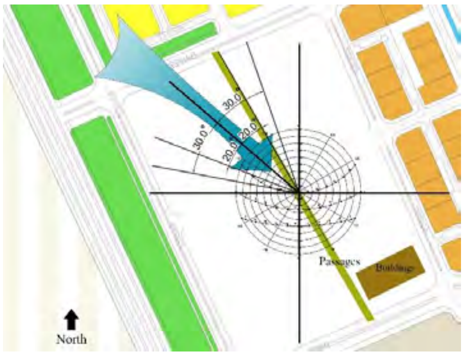

Figure 13-passage's orientation by 20 degrees from the wind direction.

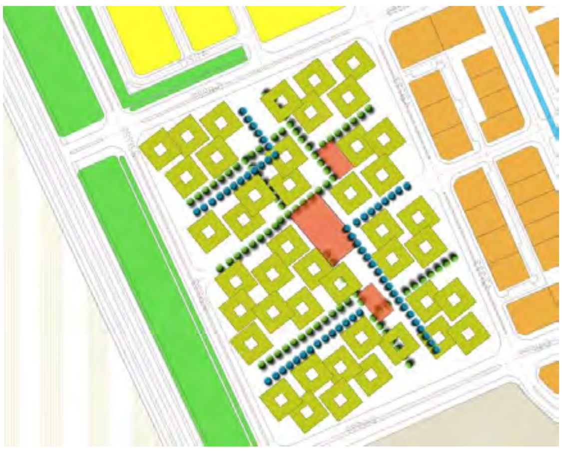

Figure 14- Creation porous texture to cross the wind on all fronts.

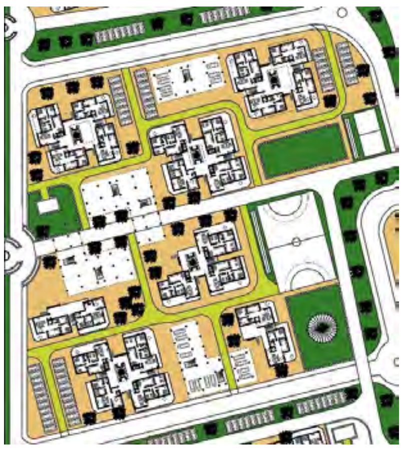

Figure 15-a part of the complex.

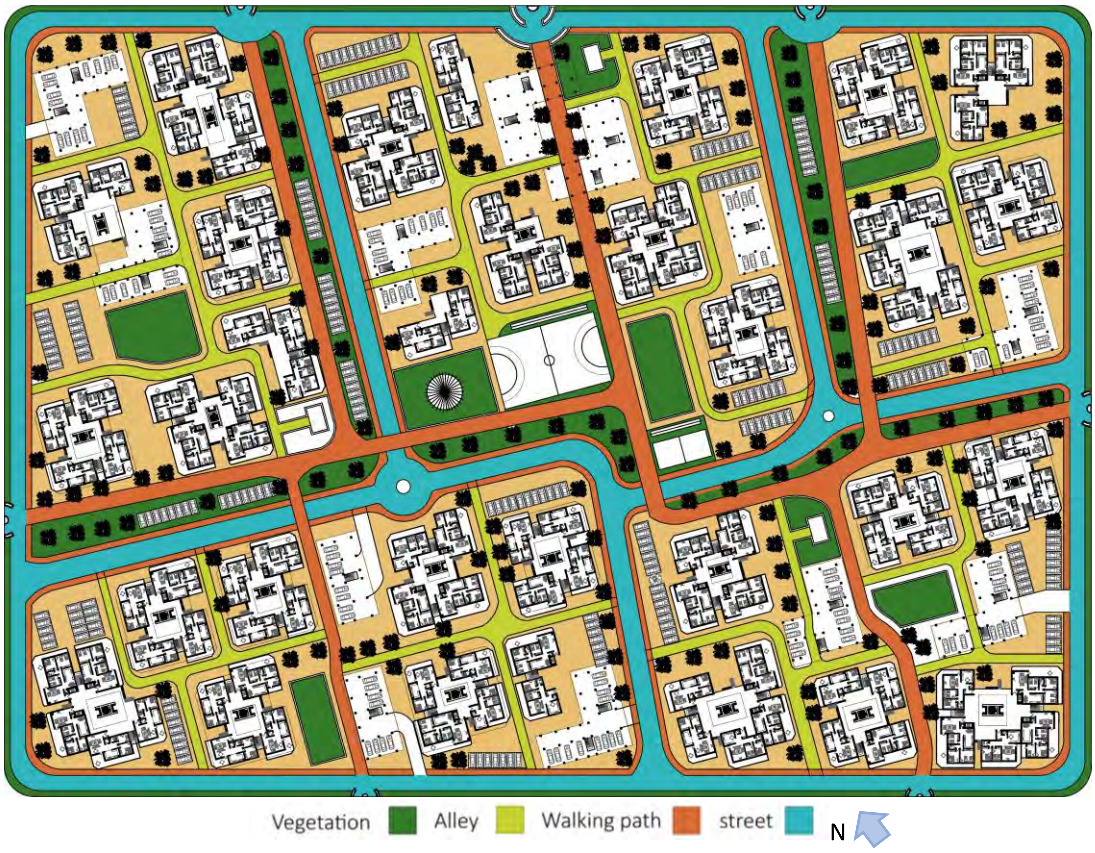

Figure 16- residential complex (ground floor).

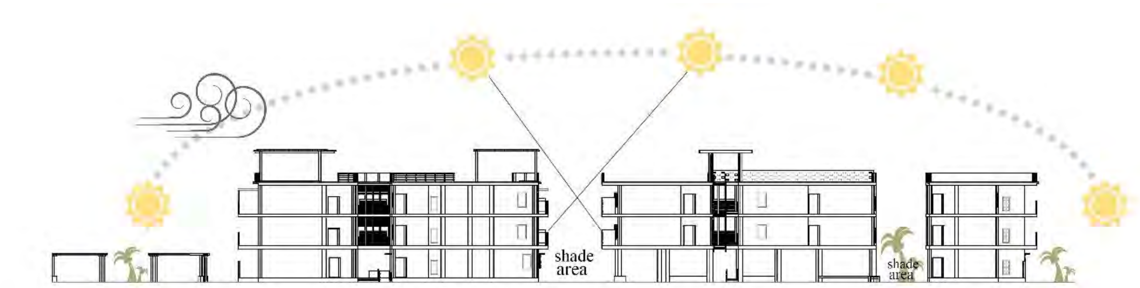

Figure 17- using of trees for shading.


Figure 18- Placement of openings in the (north shade by the veranda around the building elevation).


Figure 19- Creating openness on the floor to convey the wind into the block (South elevation).

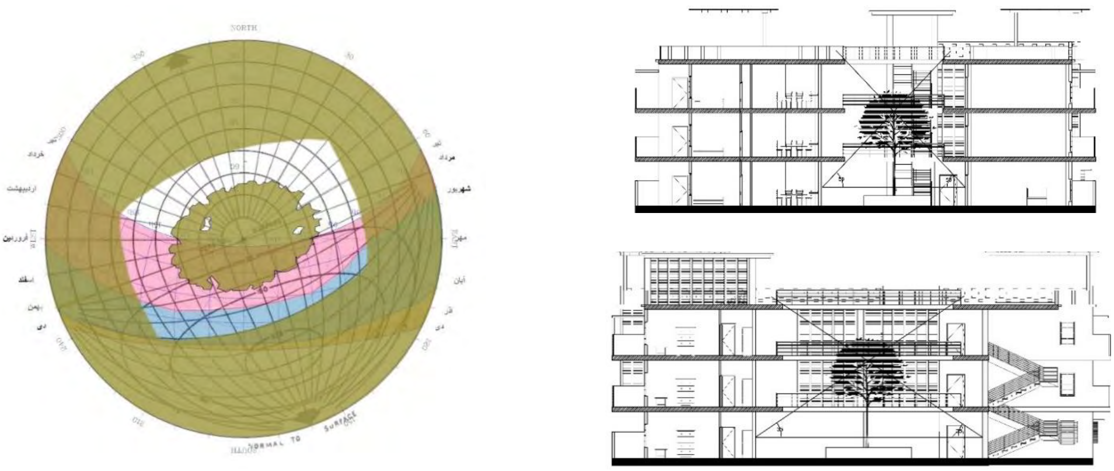

Figure 20- shadow mask and a section of a block in residential complex.

In this design Use awnings and balcony around the building in addition to shading on the building's wall also cause a shadow on the road and reduces the temperature of the building and its surroundings.

A central courtyard for shading on public space used by all units. Figure20

Conclusion

Creating the proper microclimate, and comfortable thermal conditions in open spaces requires a precise study of the climatic parameters such as temperature, humidity, radiation, the wind and other associated indicator. In this article, by studying climatic factors and historical fabric of Bushehr, solutions to create a proper microclimate around the buildings and thermal comfort in open spaces are recommend. Defining specific layout and direction of the streets by considering the prevailing wind flow, shadings on the building's facade, utilizing shaded and covered passages and walkways in open spaces, using vegetation, creating a central courtyard for shading on the buildings and conducting the wind are the considered solutions for this case study design.

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Finite Element Simulation of cool Roof Energy Efficiency for Passive Cooling in Iberian Peninsula

Antonio Domínguez Delgado[1], Carlos Antonio Domínguez Torres[2] and Samuel Domínguez Amarilho[3]

[1] Escuela Técnica Superior de Arquitectura de Sevilla (Spain), e-mail: domdel@us.es;
[2] Escuela Técnica Superior de Arquitectura de Sevilla (Spain), e-mail: cardomtor@alum.us.es
[2] Escuela Técnica Superior de Arquitectura de Sevilla (Spain), e-mail: sdomin@us.es

Abstract: Passive design strategies in Architecture are highly sensible to local climatic conditions, so techniques that work in some climatic context may be inefficient in another one, as it is the case of cool roofs for passive cooling. Cool roofs can be useful in climates with a large number of sunshine hours and thus with a high solar radiation throughout the year as it is usual in Southern Spain. In some other areas of the Iberian Peninsula, the energy efficiency of this kind of roofs for passive cooling is not clear. In this work, the thermodynamic behavior of a cool roof is analyzed in three typical climatic context of the Iberian Peninsula: Mediterranean climate in the south, Continental climate in the center and Atlantic climate in the north, during a whole typical climatic year. The thermodynamic balance of the cool roof was compared with the balance for a standard tiled roof. We conclude that the analysed cool roof provides substantial energy savings in the Mediterranean climatic context when compared to a standard roof, but its use in areas of colder climatology should be evaluated with caution due to the heat gain penalty that cool roofs produce during the heating season.

Keywords: *Energy efficiency, passive cooling, cool roofs, Finite Element, fluid dynamic*

Introduction

Over the last years, interest in the development of passive systems for heating and cooling has experienced a remarkable rise because of the need to decrease the energetic costs in the thermal conditioning of buildings. This way, extensive research in the field of energy efficiency has focused in the use of techniques that take advantage of environmental and climatic resources in a suitable form.

In hot climates, the high energy consumption needed to get internal comfort in buildings during the hot season poses a major problem. Hence the convenience of implementing techniques that minimize the cooling load. Among the various existing passive cooling techniques, in the present work we focus on a specific case of Cool Roof. A Cool Roof is a roofing system able to reject solar heat and keep roof surfaces cooler even with sunny weather. Last is possible because the properties of the used materials, which reflect the solar radiation and release the heat energy they have absorbed.

Usually a Cool Roof is a roof system with a low absorptivity coefficient for short-wave radiation from solar origin and a large infrared emittance coefficient. This way a remarkable reduction in the temperature of the roof surface is achieved, thereby decreasing the heat flow into the building.

This effect is achieved thanks to the properties of the so-called "cold materials" characterized by high solar reflectance and high emissivity for longwave radiation. In the roof studied in this work, the cold effect is achieved by applying on the roof external surface a white elastomer layer with the aforementioned radiative properties.

Since the influence of the Cool Roof affects basically the part of the building directly under it, its efficiency for tall buildings is limited to upper floors. However, the usefulness of Cool Roofs for low-rise housing and more collective use buildings, schools, office buildings, libraries, etc., is evident in the case studies included in the report "Cool Roof case studies in EU level" from the European Cool Roofs Council (Zinzi and Romeo, 2010), and in a large number of recent publications such as those of Synnefa et al. (2012) and Pisello and Cotana (2014).

In this paper the energy efficiency of the considered Cool Roof is analyzed in three locations in Spain that cover the most common climates on the peninsula: mediterranean climate (southern Spain, namely Seville city), continentalized mediterranean (center Spain, namely Madrid city) and oceanic (northern Spain, namely Santander city). Although the Iberian peninsula has other climatic zones, for brevity, only the mentioned zones are studied here because they are those that comprise a greater fraction of territory.

Due to the high levels of solar radiation and high temperatures frequent in southern Spain, the use of Cool Roofs in this area might turn out to be suitable to decrease the cooling load. However, its use penalizes the solar heat gain during the cold season since the amount of solar radiation reflected by the cover. Therefore its use should be assessed with the greatest possible precision in order to determine its suitability.

For the considered Madrid climate, the cloud cover and so the solar irradiation along the year, follow similar patterns that in Sevilla, but winters are much more cold and summer are less hot than in southern Spain, so the annual energy balance for the Cool Roofs are less favourable than the obtained for the Mediterranean climate.

Finally, in the north, the weather is often cloudy and characterized by mild temperatures with lower annual oscillations and lower levels of direct solar radiation throughout the year. This entails that the diffuse solar radiation and the flow of longwave radiation from the sky are quite high when compared to direct solar radiation. This determines the behaviour of the Cool Roof, resulting in an intermediate global energy balance when compared whit the others studied locations.

In this paper, by using computational numerical simulation techniques applied to the air fluid thermal dynamic, to the heat transfer through the roof and to the radiative exchanges, we draw conclusions about the patterns displayed by the thermodynamic behaviour of the considered Cool Roof when compared with a standard ceramic tiles roof in the analysed geographic and climatic contexts.

Case studies

For our study a detached house with two floors has been considered. The studied roofs are flat type and have the same configuration, which complies with the specifications of the Spanish Technical Code Ref. Such a configuration is described in Table 1 in which dimensioning and thermophysical characteristics of the various components of the roofs are described.

For the outer surface of ceramic tiles it is considered an absorptivity solar radiation coefficient of 0.75, while the emissivity coefficient of this layer is taken as equal to 0.83, as referenced by Gozalbo et al. (2008).

Table 1. Thermophysical characteristics of the roofs

Layer	Description	Thickness (m)	Density (kg/m^3)	Specific Heat $(J/kg\ K)$	Conductivity $(W/m\ K)$
1(Ext)	Ceramic Tiles	0.01	2000	800	1.00
2	Mortar	0.02	2000	1000	1.40
3	Protective Layer	0.02	1900	1000	1.80
4	Waterproofing (Bitominous Layer)	0.003	2100	1000	0,7
5	Separating Layer	0.02	1900	1000	1.80
6	Insulation (Extruded Polystyrene)	0.05	35	1400	0.038
7	Lightweight Concrete	0.15	1200	1000	0.57
8	Ceramic Pieces	0.30	650	1000	1.58
9 (Int)	Plastering	0.015	1000	1000	0.57

In order to transform the roof in a Cool Roof, it has been deemed the application of a white elastomer layer on the surface of the outer layer of the roof. On its technical specifications this layer provides a solar reflectance coefficient equal to 0.85 and an emissivity in the range of infrared radiation equal to 0.85.

The constructive section of the roofs are showed in Figure 1.

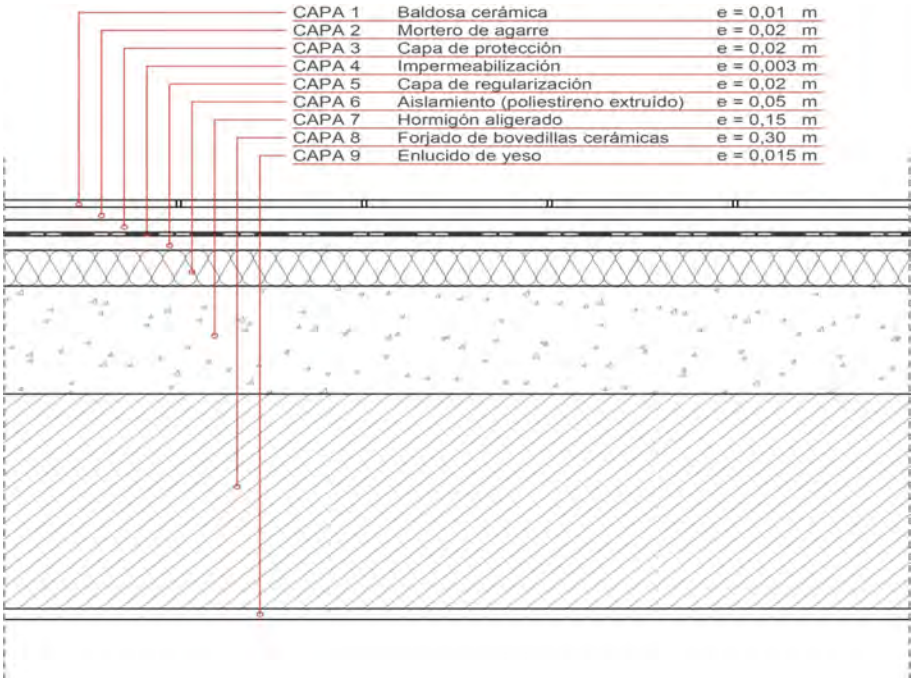

Figure 1. Constructive Section of Roofs.

Climatic Conditions

As mentioned above, passive systems are highly sensitive to local environmental conditions. In Southern Spain, and specifically in the city of Seville, clime is determined by a high seasonality. In summer daytime temperatures often reach high values, while in winter the values are significantly lower but moderate for what is common in central and northern Europe. respect it is considered usual in Europe. Solar radiation is quite high the whole year, but specially strong in summer. Meanwhile downwelling radiation is quite uniform all over the year but with a higher daily range of variation in summer which allows for nocturnal radiative cooling. Madrid has a similar seasonal behaviour but with temperatures colder in winter and summer. The solar radiation is lower than in Seville although it reaches high values the whole year and the downwelling radiation is the lowest of the three studied locations, although in summer the values of these radiation are very similar.

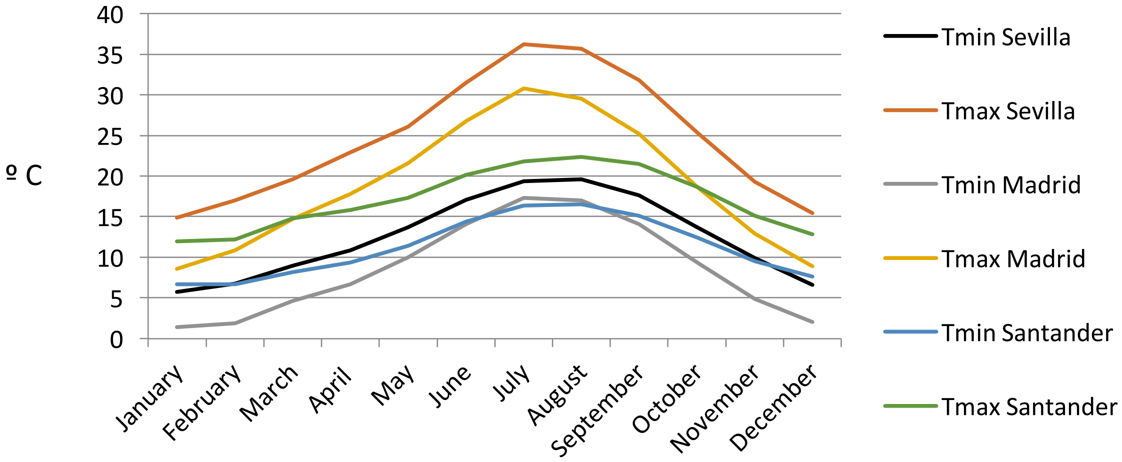

Figure 2. Averages of maximum and minimum temperatures

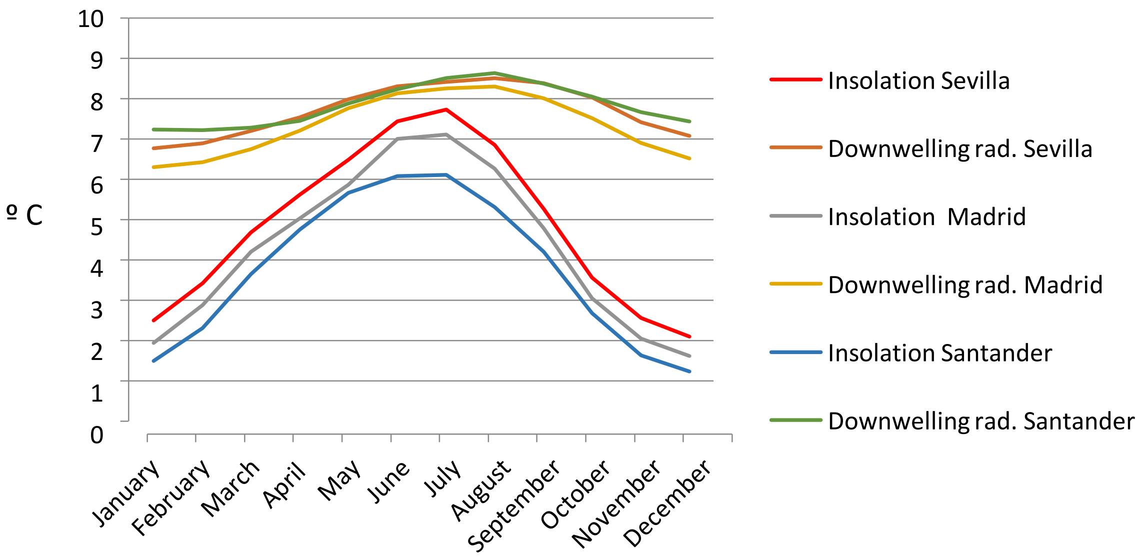

Figure 3 Monthly Averaged Insolation and Infrared Radiation Incidents on a Horizontal Surface (kWh/m2/day)

By contrast, in oceanic climates, such as the case of Santander, temperatures are more uniform throughout the year, being the daily variation range quite narrow. The temperatures do not change so strongly throughout the year as it does in Seville and Madrid and the sky is often cloudy that implies less direct solar radiation but higher values of infrared sky radiation that for the other cities.

Behaviours of the temperatures and the radiation for the three cities can be seen in Figure 2 and Figure 3 that illustrate the above.

In all cases winds are not usually strong but can range from total calm to moderate that can significantly increase heat transfer by convection between the roof and the ambiance. The studied velocities for the wind entering in the inlet of the computational domain are equal to 1, 2 and 4 m/s, which are considered sufficiently representative of the average values given in the considered climatological frameworks.

Physical modelling

In this section a generic description of the physical problem involving the heat transfer and the movement of the air mass is set out. Specifically, the heat transfer in the roofs are determined by:

- Heat gain on the outer slab due to solar irradiation.
- Heat exchange by radiation between the outer surface and the sky.
- Heat exchange by convection between the outer surface and the ambient air.
- Heat transfer by conduction through the layers of the roof.
- Heat exchange by convection and radiation between the internal surface of the roof and the interior of the building.

Other possible factors such as radiative exchange between the roof and adjacent buildings or vegetable masses, even terrain, higher than the studied building, have not been taken into account in this study for the sake of brevity.

In order to establish the physical model it must be taken into account that the equations describing the air flow, the equation for energy transport by the air flow and the heat transfer equations through the different layers of the roof must be solved in every time step. Likewise the radiative exchanges must be computed in each time step in order to adequately approximate the heat transfer through the roof.

Convective heat transfer coefficients

Convective heat transfer coefficient for external building surfaces is essential in order to calculate heat gains and losses from the roof to the ambiance air. Following the recommendations of Hagishima and Tanimoto (2003) for low-rise buildings, we have considered the coefficient value equal to

$$h_c = 8.18 + 2.28\, U_R \quad W/m^2K$$

where U_R is the velocity in m/s measured $0.6\, m$ away from the external roof surface. Since according to the authors this value is calculated specifically for convection heat transfer on the flat roof of a building with two floors, it adequately matches our case study. This correlation allows a more accurate calculation of the convective coefficient h_c because it takes into account the wind speed calculated next to the roof surface by solving the Navier-Stokes equations instead of employing the wind speeds provided by weather stations as it is usual in energy simulation programs.

Internal roof surface energy balance calculation is made by taking a comfort room temperature T_{room} constant for each season. Then we calculate the exchange of heat by convection and radiation between the internal roof surface and the room by using a mixed convective-radiative transfer coefficient given by $h_i = 8\ W/m^2K$, which is usually recommended in the technical specifications for this kind of indoor heat exchange. The values for T_{room} are usually taken like the temperature of indoor comfort.

Estimation of the downward long-wave radiation of the sky

An essential difference between the two types of radiation affecting the roofs is that solar short wave radiation takes place only during daylight hours and thermal downwelling radiation is present throughout the whole day. So, although this radiation is usually named nocturnal radiation, it takes place even during daylight hours, although at night the thermal radiative exchange is usually negative, that is, more longwave radiation is emitted that received by the roof giving rise to the so-called radiative cooling. Hence the need of a calculation as accurate as possible of this kind of radiative balance.

The presence of clouds significantly affects this type of radiation, increasing its value when the clouds have a higher density and a lower height.

A correlation quite used in such situations is the one presented by Goforth et al. (2002). Their model is a variant of the Swinbank model and is given by the following expression:

$$Q_{sky} = (1 + KC^2)\, 8.78\, 10^{-13} \quad T_{amb}^{5.852} \quad RH^{0.07195}$$

Where K is a parameter that depends on the height of the cloud layer, C is the percentage of cloudiness, being 0 for fully clear skies and 1 for completely cloudy skies and RH is the relative humidity. For this purpose we have used the values provided by different climatic organisms: the Spanish Meteorological Agency, the Meteorological Services of the National Aeronautics and Space Administration (Nasa) .

The obtained monthly average values for shortwave and longwave radiation are showed in Figure 3, for the studied geographical locations.

Numerical simulation

The numerical simulation of the flow air has been made by using a FEM discretization of the thermodynamic equations of NavierStokes. The free code FreeFem++ software, from the french "Institut National de Recherche en Informatique et en Automatique" (INRIA), has been used for the computational implementation of the considered discretizations.

The problem has been solved in a time period of one week for each month of the year, making use of the typical meteorological monthly data for every month. The time dependent problem has been solved by using the non-stationary equations of Navier-Stokes for the fluid thermodynamic dynamic and the non-stationary equations of heat conduction through the different layers of the cover. To solve the equations of fluid dynamics it has been used the $k - \varepsilon$ model for turbulence. This is necessary due to the characteristics of the problem in which the air flow over the roof of the building presents high Reynolds values that make necessary modelization of the turbulence.

At each time step the energy balance for radiation and convection in the interior and exterior surfaces of the roof are taken as boundary conditions.

Results

In order to calculate the heat flows through the roofs, constant temperatures inside the building have been considered for each calculation period. This constant temperature is the comfort temperature and it has been taken equal to 22 °C for winter months, 23 °C for spring and autumn and 24°C for summer.

Monthly heat flux

In Figures 4 and 5 monthly flows of heat in kWh/m2 are shown for the Cool Roof and for the ceramic tiles roof for different wind speeds. Positive values represent heat flux into the building and negative values outward heat flux.

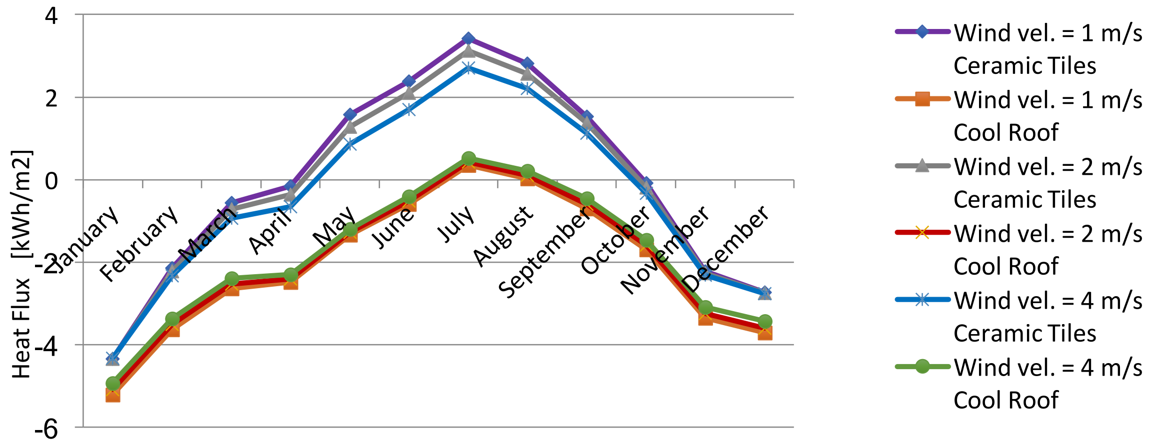

Figure 4. Monthly heat flux (kWh/m2) in Sevilla

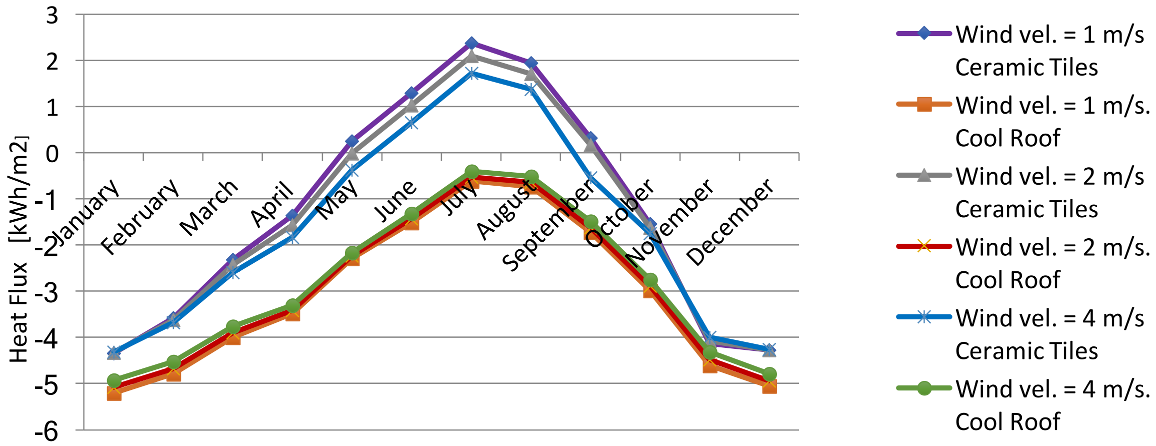

Figure 5. Monthly heat flux (kWh/m2) in Madrid

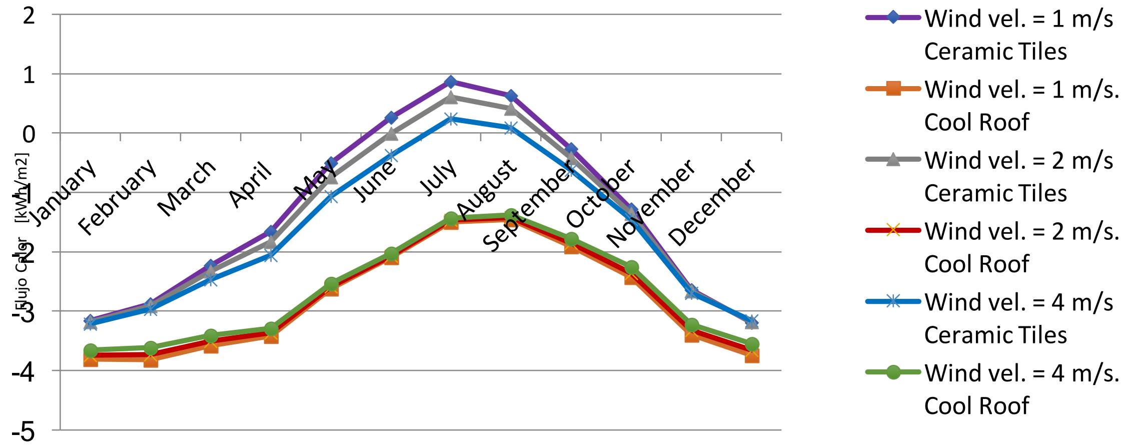

Figure 6. Monthly heat flux (kWh/m2) in Santander

It is noteworthy that the curves of heat flux for the Cool Roof are lower that the ceramic tiles ones for the whole year and for all the wind velocities. For the cool roof, only in Seville there is some positive flux in summer, whereas that for the other locations, the cool roof provides negative flux for the whole year. The effect of the wind velocity is only noticeable for the tiled roofs and in summer, when the increase of the velocity reduces the heat gain. No remarkable effect is observed for the cool roof.

Heat flux yearly balance

In Figures 4 the heat flux yearly balance for the Cool Roof and the ceramic tiles one are shown for the analysed locations for a wind velocity of 2 m/s which is close to its yearly average. For the city of Seville, the global balance doesn't take account of the heat loose in the warm months because this fact even contributes to increase the thermal comfort in such months.

The obtained results show for Madrid and Santander a higher heat flux through the Cool Roof than through the classical ceramic tiles roof. Only for Seville we find a yearly heat flux reduction because the positive balance between the cooling savings in summer and the heating penalization in winter.

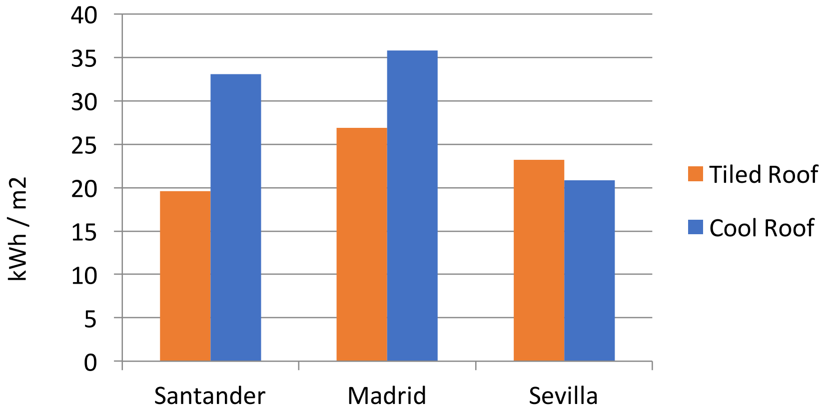

Figure 7 . Heat flux yearly balance

Conclusions

It can be established as a final conclusion that among the analysed locations, only for the city of Seville the studied Cool Roof provides energy savings. Instead for Madrid and Santander, the Cool Roof increases the energy consumption in order to get thermal confort indoor. However, other possible configurations of this kind of roof should be studied before to reject its use in cities with high levels of insolation like is the case of Madrid. However, its use in zones of colder climatology should be evaluated with caution due to the penalty in terms of the heat gain from a radiative source which is produced by this type of roof during the cold season, although in the light of climate change it should become clear, that the need for cooling most likely will increase, and that 'cool roofs' might be one part of potential measures to deal with increasing temperature levels.

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Design to Thrive

Taxonomy of Sustainable, Responsive and Adaptive Façades

Nastaran Deljavan[1] and Soofia Tahira Elias-Ozkan[1]

[1] Department of Architecture, Middle East Technical University, Ankara, Turkey,
deljavan.nastaran@gmail.com; soofia@metu.edu.tr

Abstract: Sustainable facades can be classified from many points of views. One may look at them according to their bioclimatic, energetic or technological properties; which in turn may change according to the geographic location or climatic zones, in which the building is to be constructed. Facades of high performance buildings may incorporate active or passive systems; and bioclimatic features having single, double or multiple skins. They may be completely or partially static or kinetic; stationary or dynamic; rotating, sliding or folding; with fixed or movable shading. The façade structure may be made of concrete, timber or metal with glazing, shutters, screens or trellises. The glazing may be clear, tinted or photo chromic; or it may be filled with a gas or a phase change material. In other words there are many different approaches to façade design for sustainability. This paper shall present the taxonomy of façade systems based on a survey of more than fifty buildings from around the world, which claim to be sustainable, low-energy, bioclimatic or green. Such a classification will be helpful in matching the objectives of façade design with appropriate design alternatives to achieve them.

Keywords: Sustainable facades, Responsive facades, Adaptive facades, Dynamic facades, Stationary facades.

Introduction

Responsive or adaptable building facades are being designed, developed and installed to lower energy consumption and increase human comfort at the same time. Ideally, the aim of façade design should be to improve the building's performance by providing thermal, visual, and acoustic comfort as well as a high level of indoor air quality for the health and well-being of the occupants. While the aim of the whole building design should be to ensure sustainability through energy efficiency, in order to reduce consumption; and energy generation, in order to become self-sufficient. A high performance façade is one which is able to attain both goals concurrently, i.e. energy autonomy and human comfort. To this end, various strategies can be adopted to achieve better human comfort and lower carbon footprint of the building. These strategies, some of which are active measures while others are passive, have been presented in Figure 1.

New techniques are being investigated to produce buildings that are more efficient and use renewable energies to reduce their carbon footprint. The most abundant and freely available resource being solar energy, which can be harvested through the building envelope and used for providing heating, cooling, electricity and hot water. Such building envelopes are generally referred to as solar façades, and can be classified into two main groups; opaque and transparent or translucent solar facades (Guillermo Quesada. Quesada *et al.,* 2012a). Both of these groups may have single or double skin façades (DSF) and may use passive or active systems to maximize the integration of solar energy; however, both are fixed or stationary facades. On the other hand, solar envelopes are undergoing a true revolution and their performance is being improved by adding movement to the façades or their components, in order to respond to the external climatic conditions. Such envelopes, that are also called kinetic façades, either track the sun to gain more energy for the buildings or use movable devices to avoid excessive solar gains.

New technologies and materials have made innovative facade designs increasingly possible for different climatic regions and different building typologies. Hence, many high performance buildings with sustainable, adaptive and responsive façades are coming up around the world, which are unique in their design. This study was aimed at classifying such buildings, located in different geographic and climatic zones, according to the design objectives and related strategies outlined in Figure 1.

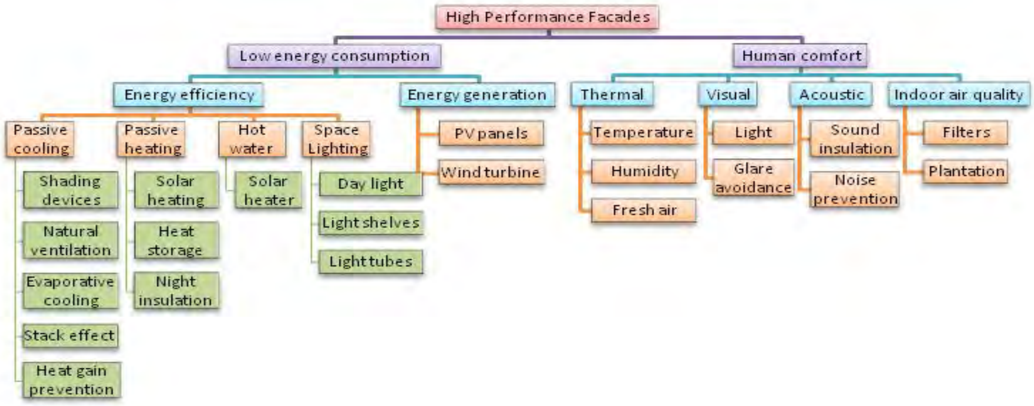

Figure 1. Design strategies for high performance façades with low energy consumption & high human comfort

Methodology

Fifty two buildings, which are acknowledged as having high performance façades that provide comfort condition and low energy consumption, were selected from literature and web-sources. These sources also included online videos and websites of the architectural firms that had designed these buildings. The 52 case-study buildings were then investigated according to the goals and related strategies presented in Figure 1 for high performance. The unique facades of these buildings were then classified according to the strategies that were considered in their design to achieve lower energy consumption without jeopardizing human comfort. These buildings were also grouped together according to 4 of the 5 main climatic zones as classified by Köppen; i.e. Tropical/megathermal climates, Dry (arid and semiarid) climates, Temperate/mesothermal climates, and Continental/microthermal climates. It was also possible to group the buildings according to dynamic or stationary façades; the former were further divided into three according to the movement of the facade elements, the whole facade or the entire building. Thereafter, all of the features mentioned in Figure 1 were identified in the fifty two building facades in order to understand which technique was used to attain higher performance. As a final step the façades were re-grouped from the point of view of these techniques and the taxonomy of sustainable façades was developed (Figure 3).

Case Studies

The fifty-two case studies belong to four of the five climatic zones defined by Köppen; there being none in the polar region. These buildings are listed in Table 1; and case study numbers assigned to them in this Table are given within curly brackets (e.g. {1,2,3..}) in the text.

Table 1. Information pertaining to the fifty-two case studies regarding their location, climatic zone, year of construction, facade typology; and web pages from where the information was retrieved.

				NO	Project Name	Project Year	Location	Climatic Zones	Links to web sources
Stationary Façades	Fixed Shading			1	US Census Bureau Headquarters	2007	Santa Monica, California, USA	Humid Subtropical Climate, Cfa	http://www.som.com/projects/us_census_bureau_headquarters
				2	Santa Monica Civic Center Parking Structure	2008	Santa Monica, California, USA	Humid Subtropical Climate, Cfa	http://www.moorerubleyudell.com/
				3	Building Block Social Nestle Graneros	2009	Graneros, O'Higgins, Chile	Cold semi-arid climate, BSk	http://www.guillermohevia.cl/
				4	3M Italia S.P.A Headquarters	2010	Pioltello, Milan, Italy	Humid Subtropical Climate, Cfa	http://www.mcarchitects.it/
				5	Burj Doha	2011	Doha, Qatar	Hot Desert Climate, Bwh	http://www.jeannouvel.com/
				6	Hanwha Headquarter Remodelling (Renovation)	1980, 2013	Seoul, South Korea	Humid Continental Climate, Dwa	http://www.unstudio.com/
				7	King Fahad National Library (Renovation)	2002, 2014	Riyadh, Kingdom of Saudi Arabia	Hot Desert Climate, Bwh	https://www.gerberarchitekten.de/
				8	New Kuwait University Sabah AL-Salem University, College of Education	2014	Shidadiyah, Kuwait	Hot Desert Climate, Bwh	http://perkinswill.com/
				9	South Australian Health	2014	Adelaide SA, Australia	Mediterranean Climate, Csa	http://www.woodsbagot.com/
				10	Juvelen- a new landmark in Uppsala (conceptual project)	2013-2018	Uppsala Resecentrum, Sweden	Warm-summer humid continental climate, Dfb	http://www.utopia.se/en/projects/juvelen
				11	Habitat Items Leon	2012	Leon, Mexico	Humid Subtropical Climate, Cwa	http://shinearchitecture.com/
				12	Rey Juan Carlos Hospital	2012	Madrid, Spain	Mediterranean Climate, Csa	http://www.rafaeldelahoz.com/
				13	John and Frances Angelos Law Center	2013	Baltimore, USA	Humid Subtropical Climate, Cfa	http://behnisch.com/ http://asg-architects.com/
				14	Soho Hailun Plaza (conceptual project)	2016	Shanghai, China	Humid Subtropical Climate, Cfa	http://www.unstudio.com/
				15	Embassy of the United States In London (conceptual project)	2017	London, England	Oceanic Climate, Cfb	http://www.kierantimberlake.com/
	Evaporative Cooling			16	Sony City Osaki	2011	Tokyo, Japan	Humid Subtropical Climate, Cfa	http://www.nikken.co.jp/en/
	Environmental Filter			17	Hospital Manuel Gea Gonzales (Renovation)	2013	Mexico City, Mexico	Subtropical Highland Climate, Cwb	http://www.elegantembellishments.net/
	Vertical Plantation			18	Green Cast	2011	Odawara-shi, Kanagawa prefecture, Japan	Humid Subtropical Climate, Cfa	http://kkaa.co.jp/
				19	Yishun Community Hospital	2012	Yishun, Singapore	Tropical Rainforest Climate, Af	http://www.gensler.com/
	Double Skin Facades			20	Unilever Haus	2009	Hamburg, Germany	Oceanic Climate, Cfb	http://behnisch.com/
				21	The Crystal and the Cloud	1010	Copenhagen, Denmark	Oceanic Climate, Cfb	http://www.shl.dk/
				22	Manitoba Hydro Place	2010	Manitoba, Canada	Subarctic Climate, Dfc	http://www.kpmbarchitects.com/
Dynamic Solar Facades	Moving Façade Elements	External Kinetic Shading	Axial Moving	23	Council House 2	2006	Melbourne VIC, Australia	Oceanic Climate, Cfb	http://www.designinc.com.au/
				24	Surry Hills Library and Community Centre	2009	New South Wales, Australia	Humid Subtropical Climate, Cfa	https://fjmtstudio.com/index.php
				25	KFW Westerkade	2010	Frankfurt, Germany	Oceanic Climate, Cfb	http://sauerbruchhutton.de/
				26	Q1 Thyseen Krupp Quarter	2010	Essen, Germany	Oceanic Climate, Cfb	http://www.jswd-architekten.de/ http://www.chaixetmorel.com/en/acma/p1/
				27	Rmit Design Hub (Renovation)	2012	RMIT University, Melbourne, Australia	Oceanic Climate, Cfb	http://www.seangodsell.com/ http://www.pta.com.au/
			Folding	28	Kiefer Technic Showroom	2010	Austria	Warm-summer humid continental climate, Dfb	http://giselbrecht.at/
				29	CJ Cheiljedang Research and Development center	2014	Seul, Korea	Humid Continental Climate,Dwa	http://www.cannondesign.com/yazdanistudio/
			Rolling	30	Mercella Niehoff School of Nursing	2012	Chicago, USA	Humid Continental Climate, Dfa	http://www.scb.com/
			Sliding and Retracting	31	Al Bahar Towers	2012	Abu Dhabi, United Arab Emirates	Hot Desert Climate, Bwh	http://www.aedas.com/en
				32	Kinetower (Kinetura) (conceptual project)	2006	Belgium, Stakendijk	Oceanic Climate, Cfb	http://www.claerhout-vanbiervliet.com/
			Sliding	33	Abu Dhabi Central Market	2014	Abu Dhabi - United Arab Emirates	Hot Desert Climate, Bwh	http://www.fosterandpartners.com/ http://www.arup.com/
		Internal Kinetic Shading (In DSF Cavity)		34	Richard J. Klarchek Information Commons	2007	Chicago, Illinois, USA	Humid Continental Climate, Dfa	http://www.scb.com/
				35	POLA, Ginza	2009	Tokyo, Japan	Humid Subtropical Climate, Cfa	http://www.yasudaatelier.com/ http://www.nikken.co.jp/en/
				36	Vivian and Seymour Milstein Family Heart	2010	New York, USA	Humid Subtropical Climate, Cfa	http://www.pcf-p.com/
	Moving Façades	Rotating	complete						
			Partial	37	Transformable Eco House (conceptual project)	2006	New York, USA	Humid Subtropical Climate, Cfa	http://www.studiodror.com/#id=architecture
				38	Gemini Haus	1991-2001	Wein, Austria	Warm-summer humid continental climate, Dfb	http://www.pege.org/
		Sliding	complete	39	Sliding House by DRMM	2006-2009	Suffolk, England	Oceanic Climate, Cfb	http://drmm.co.uk/
			Partial						
		Folding		40	Gucklhupf	1993	Vienna, Austria (Mondsee, Austria)	Oceanic Climate, Cfb	_
				41	M-vironments	2001	Valencia, Spain	Cold semi-arid climate, BSk	http://www.michaeljantzen.com/Welcome.html
	Moving Buildings (Rotating)	Fully Rotating		42	Dynamic Tower, Rotating Tower (conceptual project)	2008-2020	Dubai, United Arab Emirates	Hot Desert Climate, Bwh	http://www.dynamicarchitecture.net/
				43	Wind Shaped Pavilion By Michael Jantzen (conceptual project)		Frankfurt am Main, German	Oceanic Climate, Cfb	http://www.michaeljantzenstudio.com/home.html
				44	Heliotrop	1994	Freiburg im Breisgau, German	Oceanic Climate, Cfb	_
					Heliotrop	1994	Offenburg, German	Oceanic Climate, Cfb	_
				45	Heliotrop	1995	Bavaria, German	Warm-summer humid continental climate, Dfb	http://www.rolfdisch.de/index.php?p=home&pid=2&L=1&host=2
				46	Suite Vollard	2001	Curitiba, Paraná, Brazil	Subtropical Highland Climate, Cwb	_
				47	Rotating Dome Home	1988	Brittany, France	Oceanic Climate, Cfb	_
				48		1999	New York, USA	Humid Subtropical Climate, Cfa	_
				49	Everingham Rotating House	2002-2006	Wingham, Australia	Humid Subtropical Climate, Cfa	_
				50	RotatingHome by Johnstone	2000-2003	Southern California, USA	Humid Subtropical Climate, Cfa	_
				51	55° Dubai – Time Residences (conceptual project)	2008-2010	Dubai, United Arab Emirates	Hot Desert Climate, Bwh	http://glennhowells.co.uk/
		Partially Rotating		52	Rotating Ecohome – The Dumble Project	2010	Snelston, England	Oceanic Climate, Cfb	_

Climatic zones are important in designing efficient buildings since they influence the selection of various façade technologies. As can be seen in Table 1, 33 of high performance case study buildings are located in the sub categories of the Temperate (mesothermal) climate zone;.9 each are in the continental and dry climate zones, while only one example belongs to the tropical zone. Also, most buildings are offices or residential buildings. Four of the case studies {6,7,17,27} were building refurbishment projects where the façade was renovated to include sustainable features. On the other hand, seven of the case studies {14,15,32,37,42,43,51} are conceptual designs that have not yet been constructed. Table 1 gives us a list of the 52 projects, their location and climatic zones, as well as the web sources from where additional or important information was retrieved. This table has also grouped them according to the facade typology (static or dynamic); strategies adopted and type of movement in the dynamic façades. Figure 2 shows facade details from {8, 16, 17,18, 28, &31}

Figure 2. Façade details from some of the case study buildings: Al Bahar Towers {31}, Hospital Manuel Gea Gonzales{17}, New Kuwait University{8}, Kiefer Technic Showroom{28}, Sony City Osaki{16} and Green Cast{18}

Approaches to sustainable strategies

An investigation into the 52 case studies helped to identify the various approaches to sustainable strategies most commonly used in the world. The most important goal in the design of facades being energy efficiency was achieved by using passive strategies for cooling, heating, hot water, and space lighting. Passive cooling design was based on solar shading devices, natural ventilation, evaporative cooling, stack effect, and avoiding excessive heat gain. The techniques to integrate these strategies in the façade designs are explained in the following sections.

Shading devices

Various solar shading devices with different materials, shapes, sizes and orientations were identified in the case study buildings; some were stationary and others dynamic; some were parallel to the large glass windows to block out the sun while others were perpendicular to provide shading. Shading was generally achieved with a second layer made of translucent materials, or perforated or punched metals. Movable panels tracked the sun's position not only for shading but also for views and natural light. Some buildings {1, 2, 12, 23, 24, 25, 26, 35, 36} had movable panels or horizontal louvers that rotated around their axes automatically, according to the sun's position; this is called axial movement {27}.

In one building {31} the facade elements close and open with sliding and retracting movements and could maintain several positions between fully open or fully closed. In one case {32} the elements were made of flexible strips and their sliding and retracting movement helped to achieve a metamorphic facade. The sliding motion has also been used for moving the entire shell (walls and roofs) in order to have closed or open spaces {33}. Folding technique is also used in the kinetic facades where perforated panels as the second layers fold up mechanically according the solar position {28, 29}. In two buildings {40, 41} shading devices in the form of panels unfolded automatically or manually to block intense sunlight or strong winds; another {30} had roller blinds to do the job.

Sun screens are designed as a second layer for shielding facades, in the form of translucent, perforated, or punched panels; or as enclosing metal mesh screen with various densities in different directions. Some screens were made of glass {3, 5, 17} while one {7} was made of textile stretched on three-dimensional support system around the building.

The new self-shading facades are composed of 3D elements which are designed according to the sun's angles and movement to shade the building facade at all times. These facade elements have many different forms with inclined surfaces or curved geometries and different depths; and are designed by using parametric design software which can model optimized elements to block out direct solar radiations. {6, 8, 9, 10, 14}

Horizontal and vertical panels or louvers as fixed or dynamic elements are designed in the cavity of DSFs as shading devices, with axial, folding or sliding movement. The materials which are used as panels in the cavity are translucent, or opaque with rectangular or curved shapes. The panels track the sun's movement automatically and computerized Building Management systems control the movement of the kinetic facade elements to provide environmental comfort. {34, 35, 36} Balconies and terraces act as an environmental buffer that protects the building from climate extremes in both summer and winter. {4, 23, 19, 16}

Natural ventilation

The most efficient way to provide fresh air is to cross ventilate a building, by installing operable windows in appropriate locations; In some buildings {2, 8, 13, 30 34, 41} automated management systems regulate the openings for occupant comfort. Night purging due to temperature differences between indoor and outdoor removes the heat accumulated during the day {23}

Extending the DSF beyond the roof and installing glass vents on the roof side instead of openings on top of the facade maintains transparency of the building facade {34}; the glass vents open automatically when the warm air needs to be exhausted. In another tall building {25} with a DSF, coloured ventilation flaps enable natural ventilation by opening automatically to maintain a constant temperature and pressure within the air cavity; this protects the occupants from intense air flow due to the inconsistent pressure differentials when the inner windows are opened. This system allows controlled natural ventilation for eight months independent of outside conditions. In order to withstand the high winds from the harbour, the second layer of a building's {20} DSF is made of fluorine-based plastic instead of glass and, the width of the cavity ranges from 1meter to 1.8 meters.

Stack effect

Vertical shafts designed as a solar chimney can enhance natural ventilation due to the stack effect; this principle has been used in two of the case studies {22, 30}; one on the north façade and the other on the south. Cooler air from openings on the opposite side of the solar chimney is exhausted by using a combination of stack effect and external pressure differences in summer to decrease indoor temperatures..

Evaporative cooling

Evaporative cooling can help reduce cooling energy loads; for example in one building {3} a pool is designed next to the building facade, which cools the air passing over it. The façade also has a sun screen in front of it that works as a vertical ventilation system and draws the cooled air into the building. A building {23} in Australia has five shower towers integrated into its north façade, that draw outside air from above the street level and cool it by evaporation of the rain water collected on the roof. The cooled air is channelled into tanks to pre-cool the water coming from the chillers panels which in turn contain steel balls filled with phrase change materials to keep them cold.

The Sony building {16} utilizes specialized ceramic louvers on the façade which circulate rainwater collected from the roof and stored in tanks; when the water evaporates it causes a drop in the surface temperature of the terracotta louvers, which are coated by titanium oxide (TiO_2) for retarding moss growth. This evaporative cooling system emulates traditional Japanese evaporative cooling screens made of thin bamboo.

Heat gain prevention

One way to decrease cooling energy loads is to prevent excessive heat gain through the façades, by using glazing material and strategies appropriate to the climatic zone where the building is located. The case study buildings have used insulated glass: insulated panels: high performance double glazing: double-glazed argon-filled glass; triple-glass with 3 mm Flake's glazing; laminated glass; various ceramic fritted glass types; and multiple-layered laminated glazing with an outer layer of ETFE (ethylene tetra fluoro-ethylene).

Some buildings have used DSF or multi-layered facades with insulated glass to prevent heat gain. Openings at the top and bottom of the cavity in a stationary DSF are used for regulating natural ventilation by stack effect thus decreasing indoor temperatures during summer. In dynamic DSFs of some buildings {21, 22, 25, 35, 36}, the windows are fitted with sensors and open or close automatically according to human comfort requirements. In one building {25}, the internal layer of the DSF is opened completely by the building automation system; thus reducing the annual energy consumption for HVAC; additionally blinds or solar shading in the DSF is also very effective. One other method to avoid heat gain in summer is to install vertical gardens on the facade; some buildings {18, 19, 22} have used such green walls as the southern façade

Passive heating

Using solar energy as a heat source can reduce heating energy consumption through passive strategies, such as a DSF that acts as a passive solar-thermal collector and heats the air in the cavity. This warm air augments space heating and also acts as an insulating buffer, that helps to conserve heat energy in winter {25, 34, 30}.

Hot water

It is possible to use solar energy for heating water for domestic hot water supply or for space heating. A pool in front of one building {3} contains water that gets heated due to solar energy and is then circulated in the heating system of the building. Another building {44} has solar tube collectors as balcony railings to provide hot water that can be used for domestic hot water needs or for space heating.

Day light

Maximizing natural light in the buildings is one of the important strategies to decrease consumption of electricity. The case study buildings have transparent or translucent materials to benefit from daylight; but its ratio to opaque materials differs, hence the amount of natural light penetration from various facades is completely different. Usually the northern facade is transparent to allow ambient light inside, whereas the southern facade is more opaque to protect the building from excessive heat gain. By incorporating a courtyard the number of facades are increased in the building, thus increasing the amount of external surfaces from which the building can take in natural light {1, 4, 33}. DSFs also allow maximum daylight penetration since both skins are composed of transparent materials {21, 22, 34, 35, 36}, which is usually glass. Although in one building {20}, ethylene tetra fluoro ethylene (ETFE), which is a kind of semi-transparent foil that allows natural light penetration, was used. Another way to maximize lighting levels is through dynamic facades that use light sensors which can monitor natural light availability and adjust interior lights accordingly, to reduce energy consumption {23, 24, 28, 35}. In one building {13} automated venetian blinds are installed leaving the top one-third of the window bare to admit natural light.

Visual Comfort

Large windows or glass facades allows for a visual connection between indoors and outdoors; however they also allow excessive sunlight and solar gains. But glare from reflecting or direct sunlight causes visual discomfort and should be avoided. Three approaches for glare avoidance were identified. The first one is using suitable material which can diffuse sunlight; such as: reflective glass, laminated glass, various ceramic fritted glass types, Flake's glazing, ethylene tetra fluoro ethylene (ETFE), or coloured glass {2, 8, 11, 12, 15, 25}. The second method is to integrate fixed or dynamic sun screens made of translucent materials; perforated panels; or metal mesh screens with various densities on the building facades {3, 5, 7, 27, 28, 29}. The third solution is to design self-shading facades with curved or inclined surfaces that can also diffuse day light {6, 8, 9, 10, 14}.

Acoustic comfort

In order to achieve acoustic comfort in the building, considering sound insulation and noise prevention are useful. In some DSFs the sealed cavity between the two layers, is used as an acoustic buffer. {20, 21, 22, 25, 34, 35, 36}

Indoor air quality

Indoor air quality has been provided through air filters or façade plantation. For example, special filtering screens having five three-dimensional modules made of titanium dioxide, been designed to provide fresh air in the building. This material possesses photo catalytic and anti-microbial properties that break down nitrogen oxides and other compounds by using high UV radiation levels and transforms them into water and calcium nitrate, which are washed off by the rain. The shape of the modules for filtering air pollution and emission is designed to receive maximum sunlight {17}. In one building a regular air pollution filter was installed {20}. Another more ecological solution is to use plants as air filters; e.g. in one building Bamboo plants are grown in the triangular cavities of its DSF; air is drawn in from the top of the DSF where the plants absorb the CO_2 and release oxygen into the air.The filtered air then flows under the building to be cooled through a thermal labyrinth and then supplied to the building {24}. Meanwhile, vertical gardens on the facades of 3 buildings {18, 19, 23} have been designed to act as an air filters.

Energy generation

Generating electricity by installing photovoltaic (PV) panels or wind turbines on the building can help achieve sustainability; excess energy that is not used can be stored in batteries for use when there is no solar or wind energy available. In some buildings, PV panels are installed on their facades to generate electricity and the angles of PV panels are arranged to maximize energy production {2, 10, 15, 42}. In some buildings {6, 16}, PV panels are installed on southern facades as shading devices with an angle which is appropriate for generating electricity as well as for blocking unwanted solar radiation. In a cylindrical building {38}, its dynamic PV integrated solar facade rotates around it to follow the sun, thus producing an energy surplus over and above the building's needs. The other source for producing energy is wind turbines, which are installed on facades or roof of some buildings {42, 52}; while on another building {23} it is installed on the shafts of the building facades.

Rotating buildings and towers

All rotating buildings have a fixed central service core while the living spaces rotate around it according the position of the sun. In winter time large insulated windows capture and store maximum solar energy during the day to heat the building at night; while during summer, the building rotates to face the right direction for natural ventilation, daylight, and shade. In dome-shaped homes, vertical windows assist to get more solar energy. By rotating the building, it is possible to control indoor temperature as well as provide a change of scenery {42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52}. Except for one building {52}, the others can rotate 360 degree on their own axis with various speeds for different buildings, automatically or manually with remote control. In most of the rotating buildings, the motor sizes are small, which can work with solar energy. In the rotating towers {42, 43}, the floors rotate independently thus changing the facades constantly. The unique envelope of the Rotating Ecohome possesses a high thermal mass; since the exterior walls are made of plastic pipes with vertical ducts passing through; and heated or cooled air is blow through these ducts according to seasonal demands, in order to heat and cool the building. The energy from the roof and facade of the building is stored in the machine room for later use.

Taxonomy of sustainable façades

From the case studies around the world, we can see that high performance facades can be divided into two categories, namely: stationary facades and dynamic facades; while each category can be further divided according to the technologies utilized (Figure 3). Dynamic façades are gaining popularity because they can respond and adapt themselves to the external climatic conditions by tracking the sun's position and thus enabling passive heating, cooling, ventilation, and daylight for saving energy. In most dynamic facades, photovoltaic panels are also integrated to produce the energy required for the mechanical movement of the façade elements. Kinetic facades elements with various motions help to optimize and regulate solar heat gains, light and air quality in the buildings and act as shading devices as well as energy engines. Additionally, shading devices are also important elements in stationary facades to block or allow solar energy inside the buildings.

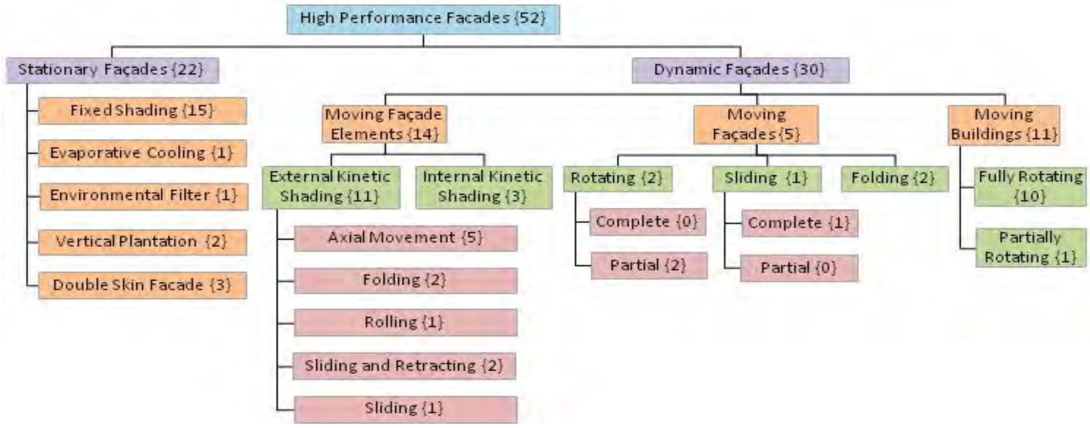

Figure 3. Taxonomy of high performance façades; numbers within brackets show the number of case studies.

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Passive Low-energy Residential Buildings in China：Features and Calculation of Energy Demands*

Wu Di[1], Wang Nan[1] and Liu Conghong[1]

[1] School of Architecture, Tianjin University, Tianjin, China, conghong_Liu@163.com;

Abstract: Passive House provides beneficial lessons to Chinese energy efficient buildings. *Passive low-energy* or *passive ultra-low energy* buildings are concepts that are developed based on PH. During 10 years of development, many passive low-energy building projects have been constructed and being accepted by more and more people. However, the energy efficiency levels of Chinese passive low-energy buildings are still to a large extent using the PH standard. Besides, energy efficiency levels of current built energy efficient buildings are not clear because of most Chinese standards do not regulate energy performances. Since energy efficiency levels are the first step to achieve the nZEB goal, this study aims to calculate the energy demands of Chinese energy efficient buildings and passive low-energy buildings by a case study. Features of Chinese passive low-energy residential buildings will be summarized firstly, then the calculation will be conducted based on a high-rise residential building in Sino-Singapore Tianjin Ecocity (SSEC), in the cold zone of China. Six construction concepts will be modelled to represent the design patterns of Chinese energy efficient buildings as well as passive low-energy buildings. Energy demands of the six construction concepts will be calculated using PHPP.

Keywords: passive low-energy building, residential building, energy demands calculation

Introduction

Passive House（PH）is a solution for cold climate countries to reduce heating demand associated with buildings energy consumption. Under the support of Chinese government and Dena (Deutsche Energi-Agentur), China began to promote the concept of passive low-energy or passive ultra-low energy buildings to minimize the building energy consumption since 2007. During 10 years of development, there have been 37 demonstration projects constructed and the total construction area is 33,000 m^2 (2015 statistics).

The concept of passive low-energy or passive ultra-low energy buildings is developed based on the PH concepts and made some adaptive changes as Chinese climate is different from Germany. Previous studies have investigated the energy performance of passive low-energy buildings in different climate zone of China (Qiu Le,2014; Fan Yifei, 2013; Ma Yishuo, 2015). Xu Wei (2015) promotes energy performance criteria of Chinese passive low-energy buildings considering the construction technology, heating method, design layout of residential building and people’s living habits. Zhang Xiaoling (2012) points out that the expensive price of imported building components and equipment which reaches the

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requirements of PH, and the defection of construction quality are also challenges of promoting PH designs in China. Peng Mengyue (2015) suggests to dividing the PH standard to four levels, they are bronze, silver, gold, and PH from low to high. However, the four levels only regulate design strategies and energy performance are not shown.

However, researches on the energy efficiency levels are relatively infrequent seen except for the mentioned studies above. One reason is the current Chinese standards systems define energy efficiency by means of percent (which will be discussed later) and lack of regulations on the energy performances. Since energy efficiency levels are the first step to achieve the nZEB goal (M. Ferreira et al, 2016). This study aims to calculate the energy demands of Chinese energy efficient buildings and passive low-energy buildings. Features of Chinese passive low-energy residential buildings will be summarized firstly, then the calculation will be conducted based on a high-rise residential building in Sino-Singapore Tianjin Ecocity (SSEC). Six construction concepts will be modelled to represent the design patterns of Chinese energy efficient buildings, including passive low-energy buildings. Energy demands of the six construction concepts will be calculated using PHPP.

Features of Chinese passive low-energy residential buildings

According to standard GB50176-93, China was divided into five zones in terms of climatic differences. They are severe cold, cold, hot summer cold winter, hot summer warm winter and mild. The following discussions are based on cold zone since heating demand account for a large proportion of total energy demands in this zone.

Architecture design

Compact high-rise buildings are predominantly built in China with the background rapid increase of urban population and the consequent shortage of urban land. In Beijing, the ratio of high-rise buildings has already increased to 50%-53% during 2000-2003, among which 16-20 storey buildings are the most common type (Jin Haiyan et al, 2012). Therefore, many passive low-energy demonstration projects are equally high-rise buildings, such as Zaishuiyifang C15# in Hebei(Figure1). The standard floor plan(Figure2) contains 3 apartments with a traffic core. Living room and main bedrooms usually locate in the south while kitchen, study room and secondary bedrooms in the north. All subordinate rooms are accessible from the central living room. No bay windows can be seen in this plan since bay windows are not encouraged for energy-efficient reasons since 2006.

Figure 1. Appearance of Zaishuiyifang C15#（18 storey）

Figure 2. Standard floor plan（the fifth storey）

Energy consumption

The interior environment, ventilation, heating and cooling method of Chinese passive low-energy buildings have some localized features due to Chinese people’s living habits or building standards (Table1). Compared with PH, the interior environment comfort level of

Chinese passive low-energy residential building is lower and natural ventilation is the primary way to solve the overheating problems in summer. People will open windows irregularly even during heating period according to a questionnaire survey (Chen Qingzhou, 2015). District heating is used with Split air conditioner is the most common cooling method. The cooling energy consumption of Chinese residential buildings varies radically due to different user behaviour and operating modes of HVAC systems. It ranges significantly from 164-2519 kWh/apartment·a (THUBERC , 2013).

Table 1. Design parameters comparison of PH and Chinese passive low-energy residential building

Design parameters	PH standard	Chinese passive low-energy residential building	
		Design or system choice	Reference
Interior environment	20℃ / 25℃ (winter/ summer)	▪18℃/ 26℃(winter/summer for bedroom and living room)	▪China energy efficient standards JGJ26-2010 and DB29-1-2013
		▪20℃ / 26℃(winter/summer)	▪China passive low-energy standards DB13(J)/T177-2015 and DB37/T 5074-2016
Ventilation	mechanical ventilation	▪natural ventilation primarily, even during heating period ▪fresh air mainly by opening windows and exhaust fans installed in toilet or kitchen	▪Chinese living habits and questionnaire survey
Heating	compact unit	▪district heating all time and all rooms in an apartment during heating period ▪or compact unit	
Cooling	compact unit	▪split air conditioner separately in each room ▪or compact unit	

Design parameters

The design of Chinese residential buildings shows obvious correlation with energy efficiency goals. The national energy efficiency goal of China is 65%, which means the design building should consume 65% less heating energy than the reference building (a typical residential building in the cold zone of China built in 1980-1981). Some local standard, such as Tianjin, has increased the goal to 75%. Passive low-energy standard such as Hebei standard is developed based on German basis PH criteria. The requirements of airtightness, envelope and energy performance are in line with PH criteria. The requirements of building thermal performances and airtightness are obviously higher than current national and local standard (Table 2).

Table 2. Energy efficiency design parameters

Design parameters		National standard (cold zone)	Local standard (Tianjin)	Passive low-energy standard (Hebei)
Height（m）		—	h≤3.0	—
Shape coefficient		A/V≤0.26	A/V≤0.26	—
Heat transfer Coefficient ($W/m^2·K$)	external wall	K≤0.70	K≤0.45	K≤0.15
	roof	K≤0.45	K≤0.25	K≤0.15
	external window	K≤3.1	K≤2.3(south) K≤1.8(other direction)	K≤1.0
Airtightness		level7: 0.5 < q1≤1.0	level7: 0.5 < q1≤1.0	$N_{50}=0.6h^{-1}$
Reference		JGJ 26-2010 GB/7106-2008	DB29-1-2013 GB/7106-2008	DB13(J)/T177-2015

Methodology

Based on the above analysis, six construction concepts can be extracted to conduct the following calculation (Table 3). These construction concepts are marked with specific energy efficiency goals, envelope performance, air tightness and ventilation mode. The analysis in Table1 and Table2 provide beneficial reference to these settings.

Case1 and Case2 are set to achieve a 65% energy efficiency goal. Case3 is set to achieve a 75% energy efficiency goal. Case4 is set based on project Zaishuiyifang C5#, first labelled passive low-energy building in China. This kind of setting is to represent a higher level of energy efficient buildings, with envelope very closed to PH but is natural ventilated and the common construction quality. Case5 and Case6 are set to achieve PH standard. The only difference lies in the ventilation mode. In Case5, hygienic air is provided by natural ventilation, while in Case6, the hygienic air is provided by a mechanical ventilation system with heat recovery. The envelope parameters of Case2 are the same with Case1, but the design layouts are optimized.

Since airtightness is hard to determine and lack measurement data, the n_{50} value of Case1, Case2 and Case3 is calculated based on GB/T 7106 level7, which represent a common level of airtightness of residential buildings, and convert to n_{50} according to the research of Feng Xiaohang (2014). The airtightness of Case4 is set as $2h^{-1}$, which is the medium level of double glaze windows according to EN12831. The airtightness of Case5 and Case6 is set as $0.6h^{-1}$.

Table 3. Six construction concepts of Chinese energy efficient buildings

Case	1	2	3	4	5	6
Model	Original	Optimized	Optimized	Optimized	Optimized	Optimized
Energy efficiency level	65%		75%	Zaishuiyifang C15#	natural ventilated PH	PH
Interior environment(C°)	18/26(winter/summer)					20/25(winter/ summer)
External wall ($W/m^2 \cdot K$)	30mm EPS-insulation U=0.69		75mm EPS-insulation U=0.45	150mm EPS-insulation U=0.3	250mm EPS-insulation U=0.150	250mm EPS-insulation U=0.150
Window	double glazing, 12mm Ar		double glazing, 12mm Ar	tripe glazing low-e, 9mm Ar	tripe glazing low-e, 12mm Ar	tripe glazing low-e, 12mm Ar
$U_g/U_f/U_w$ ($W/m^2 \cdot K$)	2.44 / 2.6 / 2.5		1.5 / 2.1 / 1.8	0.88 / 1.5/ 1.0	0.735 / 1.0 / 0.8	0.735 /1.0 / 0.8
SHGC	0.76		0.57	0.48	0.46	0.46
$n_{50}(h^{-1})$	4		4	2	0.6	0.6
Vent	only window ventilation		only window ventilation	only window ventilation	only window ventilation	balanced PH ventilation with HR

Numerical models will be built by Sketchup with DesignPH plugin. Calculation is conducted by Passive House Planning Package (PHPP), a comprehensive Excel workbook that was specially developed for planning Passive Houses.

Calculation of Energy Demands

Numerical model

Calculations are performed based on a high-rise residential building in Sino-Singapore Tianjin Ecocity (SSEC). The building can represent the common design of high-rise residential buildings in the cold zone of China. The 16-storey building contains four apartments per story, each with living area of 60-90m^2. An optimized model is formed by decreasing room height and heat loss form factor (ceiling and floor not included). The position of windows basically remains the same as the original model (Table4).

Table 4. Description of numerical models.

Model	Plan	Simplified appearance
Original Height:3.1m Areas:311m^2	Heat loss form factor (ceiling and floor not included):1.01	
Optimized Height:3.0m Areas:299m^2	Heat loss form factor (ceiling and floor not included):0.9	

Weather data other simulate assumption

Calculations are based on the PHPP climate data of Tianjin. This study considers the standard floor plan of an intermediate story. Details of a possible basement, the ground floor and the top floor are ignored in this analysis. Heat loss from the ceiling and floor is not considered so the U value of the ceiling and floor of the intermediate story is set as 0.25 for case1-case6. Geometric thermal bridges are ignored since they are not the main factors considered in this paper. Install thermal bridges are set 0.04 for all cases. The shading of surrounding buildings and window shading are not considered in this study.

Results and discussion

This study mainly investigates the heating and cooling energy consumption. Lighting, DHW, and auxiliary electricity energy consumption are not considered.

Figure3 depicts the heating and cooling demands of case1 to case6. We can see that heating is the main energy consumption for the cold zone of China compared to cooling and the total energy demands decrease significantly from case1 to case6 due to the decrease of heating demand. Only the energy demands of case6 almost achieve the PH standard. However, energy demands of the other five cases also make sense since they help clarify the energy efficiency levels.

The energy demands of 65% energy efficient buildings of China (case1) are 72 kWh/m^2·a for heating and 23 kWh/m^2·a for cooling. After optimizing the geometric factors (case2), the heating demand decreases 4% to 69 kWh/m^2·a but the cooling demand increases 8.7% to 25 kWh/m^2.a. The decrease of heating demand is predictable because the combined effect of optimizations in room height and heat loss form factor. However, total energy consumption does not show an obvious decrease in an optimizing model. Therefore, we can conclude that for conventional 65% energy efficient residential building designed according to JGJ26-2010, only optimize geometric factors such as heat loss form factor, room height or WWR are not enough to decrease total energy demands, further optimizations of envelope must be performed to achieve a higher energy efficient design.

The energy demands of 75% energy efficient buildings of China (case3) shows evident decline compared to Case1 and Case2. Energy demands are 54 kWh/m^2·a for heating and 21 kWh/m^2·a for cooling. Transmission heat losses through envelope decrease 27% compared to case1, which is the main reason of the decreasing of heating demand.

The energy demands of Zaishuiyifang C15# (case4) is 36 kWh/m^2·a for heating and 17 kWh/m^2·a for cooling. Heating demand decreases 50% compared to case1. Therefore, increasing the thermal performance of envelope as well as enhance airtightness are effective strategies to half the energy demands of current 65% energy efficient buildings. However, we can see that although the energy demands show an obvious decrease but still deviate from 15 kWh/m^2·a regulated by PH standard. The reason may be in the natural ventilation mode and the air tightness exceeding the recommended level(0.6h^{-1}). However, whether it is necessary to achieve this standard is another problem worth discussing.

For passive low-energy building which the envelope and airtightness achieve the PH standard but is natural ventilated (case5), energy demand is 21 kWh/m^2·a for heating and 16 kWh/m^2·a for cooling. The heating demand further decreased to 11 kWh/m^2·a after equipping a mechanical ventilation system with heat recovery (case6). However, cooling demands of case5 and case6 are basically the same, both 16 kWh/m^2·a. With the same air change rate, ventilation heat losses through mechanical ventilation system with heat recovery is near 50% less than natural ventilation through windows. Therefore, ventilation heat loss is the most important factor that affects heating demand for an apartment with high performance envelopes.

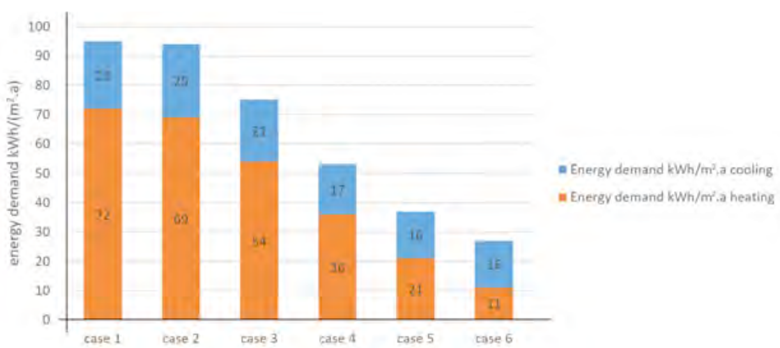

Figure 3. Energy demands of Case1 to Case6.

The comfort level presents a different trend from energy demands(Figure5). The discomfort level of over-humidity showed a basically increasing trend from case1 to case6. However, the discomfort level of over-heating has an inflection point. The natural ventilated passive low-energy building (case4) shows the lowest over-heating rate. PH, no matter natural ventilated (Case5) or with mechanical ventilation system (Case6), have the highest discomfort level though their energy demands are very low.

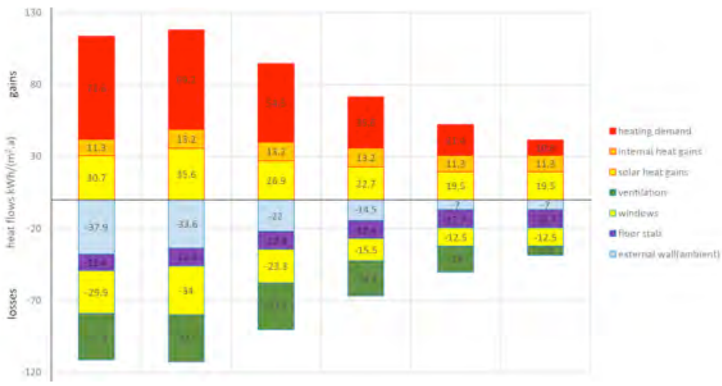

Figure 4. Energy flows of Case1 to Case6 in heating period.

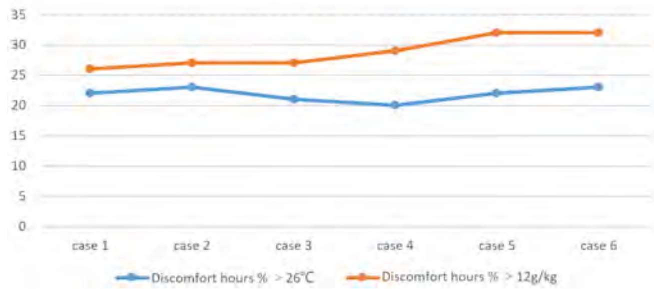

Figure 5. Discomfort hours of Case1 to Case6.

Conclusion

Six construction concepts were set according to the features of Chinese passive low-energy buildings. The energy demands are calculated.

For current 65% and 75% energy efficient Chinese residential buildings, the energy demands are 54-72 kWh/m^2·a for heating and 21-23 kWh/m^2·a for cooling. And the results show that further optimizations of the envelope must be performed to reach a higher energy efficiency level, instead of optimizing heat loss form factor and room height.

For passive low-energy residential buildings designed and constructed according to PH principles. The energy demands are calculated considering the impact of natural ventilation. Results show that for natural ventilated PH, the heating demand is 21-36 kWh/m^2·a, the cooling demand is 16 kWh/m^2·a. The heating demand decreases to 11 kWh/m^2·a when the natural ventilation is off and replaced by mechanical systems with HR. However, the over-heating rate of a natural ventilated PH is lower than a PH equipped with heating recovery mechanical ventilation system.

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Design to Thrive

Research on winter physical environment and comfort of atrium space in public buildings in China's cold region

Yiming Du[1], Qiong Huang[1], Han Zhang[1], Nanjue Wang[1], Yu Mu[1] and Qi Zhang[1]

[1] School of Architecture, Tianjin University, Tianjin, China

Abstract: Atrium space energy consumption is an important part of public building energy consumption in china's cold region. Therefore, it also possesses huge energy saving potential. Because of the complexity functions of public building, atrium space usually have a higher demand in physical environment and comfort which are more important than the pursuit of energy saving. In this paper, the investigation focused on the winter physical environment and comfort of atrium space in hotel buildings, libraries and shopping centers. Arranged through the measured data and subjective questionnaire data, it revealed the shortage of atrium space physical environment and comfort in cold region. The main conclusions of this paper include: 1. According to the research, the average air temperature of atrium space in the public buildings is 22° in winter. This temperature stays in a relatively comfortable range. 2. The average humidity of the public buildings atrium space is less than 15%, which cannot display in the measuring instrument. 3. The average illumination of the public buildings atrium space is 1279 lux. Although 1279 lux stays in a comfortable lighting condition, its distribution is not uniform.

Keywords: Winter Physical Environment, Atrium Space, Public Buildings, Cold Areas in China

Introduction

The energy consumption in public buildings is much higher than that in the residential buildings. According to the data of China Building Energy Consumption Report 2014, public buildings' energy consumption is about three times that of the residential buildings. Compared with residential buildings, the atrium space is a unique part of the public building space types, which meanwhile means that the huge energy consumption of public buildings may be related to it.

As to the indoor comfort level of public buildings, China has the relevant standard gb//, in which indoor environment comfort indicators of public buildings with different sizes, scales and categories are limited. However, the design of public buildings is mostly in accordance with the "function-form" mode, with less consideration of the physical environment. Usually, high comfort level is achieved through air conditioning and heating systems and the artificial lighting system. The architectural design without the physical environment taken into account and the high requirements for comfort level are bound to produce higher energy consumption.

Public buildings have many categories, and this paper selects the atriums of library, shopping center and hotel as large space research objects. The choice of the atrium of library, shopping center and hotel is firstly because these buildings are the most frequently contacted and used buildings, whose energy consumption shall be the largest; secondly, these types of buildings are more, so the larger number of samples can provide more objective research results.

Object

The goal of this paper is to find the balance between the physical environment and comfort level of atrium space of the public buildings. The physical environment data for public buildings were obtained through field measurements of nine hotels, four libraries and six shopping centers in the cold climate area. By comparing the yearly physical environmental data of the public buildings with the environmental requirements put forward in the standard, the design refinement suggestions to improve the energy consumption of the public buildings in cold areas are proposed.

Methodology

This paper is based on the field measurement to achieve the physical data about the atrium space of public buildings. Through the comparison between measured data and standard data, find where the public space in cold areas can be improved.

For the field measurement, the physical environment measurement is mainly divided into thermal environment measurement and light environment measurement: the thermal environment takes air temperature and relative humidity as evaluation indexes, with HOBO U100-003 temperature data logger to measure, while the light environment takes illumination as the evaluation index, with XYI-III full digital illuminometer to measure.

The measure points' layout of the thermal environment is divided into the basic measurement points and the additional measuring points. The basic measurement points are the four directions of each floor in the measurement area and the corresponding position of the center, avoiding the position with large fluctuation of the environmental parameters such as the air outlet, the building entrance and exit; and as the supplement to the basic measurement points, additional points can provide the closer thermal environment data when the atrium area is too large.

As to the measurement points' layout of light environment, select the first floor of the atrium as the measurement area, with the 2-meter grid to lay out measure points.

Figure 3-1 Layout Diagram of HOBO Basic Measurement Points

Measurements

National Standard

The thermal environment takes air temperature and relative humidity as evaluation indexes. As to the standard, Code for Design of Hotel Building (JGJ 62-2014), Code for Design of Store Building (JGJ48-2014) and Code for Design of Library Building (JGJ 38-99) are the main reference, with relevant provisions of Design Standard for Energy Efficiency of Public Buildings (GB50189-2015) and Design Code for Heating Ventilation and Air Conditioning of Civil Buildings (GB50736-2012) as the comprehensive reference. And thus the thermal environmental assessment criteria are set as follows:

Hotel: air temperature at 20~22℃, and relative humidity ≥30%.

Shopping Center: air temperature at 18~24℃, and relative humidity ≥30%.

Library: Summer: air temperature at 18~20℃, and relative humidity of 40%～60%.

The light environment takes the illumination value as the evaluation index. Taking Standard for Daylighting Design of Buildings (GB50033-2013) and Standard for Lighting Design of Buildings (GB50034-2013) as reference standard, the light environment evaluation criteria are set as follows:

Hotel: Natural lighting: side lighting illumination of not less than 300lx, the top lighting illumination of not less than 150lx; Artificial lighting: no less than 200lx.

Shopping Center: General store business hall for 300lx, high-end business hall for 500lx, high-end hall for 200lx, corridor and mobile areas for 100lx.

Library: Natural lighting: reading room, side lighting of open-shelves stacks is not less than 450lux; the top lighting is not less than 300lux; side lighting of catalogue room is not less than 300lux; top lighting is not less than 150lux; side lighting of stacks and traffic is not less than 150lux ; and the top lighting is not less than 75lux;

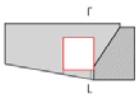
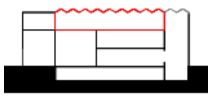
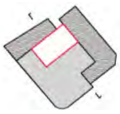
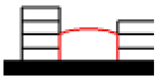
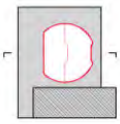
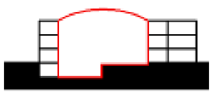
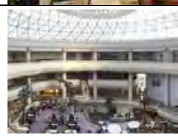
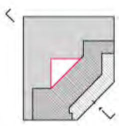
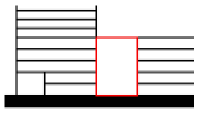
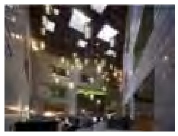
Cases Selection

The standard for the choice of the atrium cases is determined as top surface lighting, with 75% of the enclosed surface as non-external wall surface. According to the above criterion, we have selected nine hotels, four libraries and six shopping centers in the cold climate area as the research objects.

As the physical environment involves the sensitive information of the hotels and other public buildings, the article takes H1-H9 as hotel cases number; L1-L4 as library cases number; and S1-S6 as shopping center cases number.

Table 1 Diagram and Information of Hotel Sample

Table 1 Diagram and Information of Hotel Sample

Sample NO.	Spatial Diagram		Spatial Interface		Picture
	Plane	Profile	Lighting Form	Sunshade	
H1			Skylight Lighting	Yes	
H2			Skylight Lighting	Yes	
H3			Skylight Lighting	No	
H4			Skylight Lighting	No	

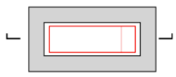
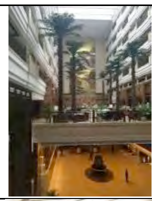
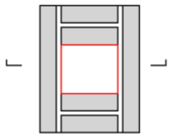
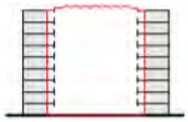
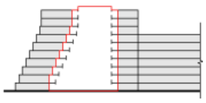
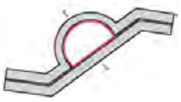
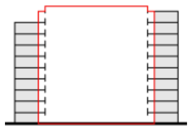
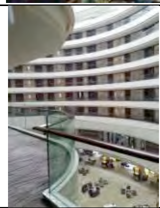
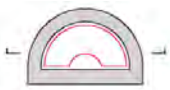
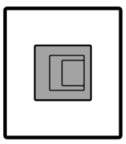
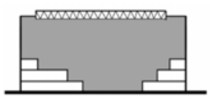
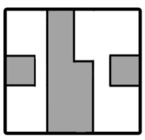
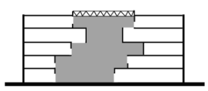
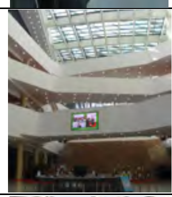
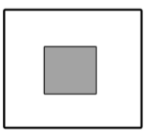
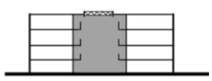
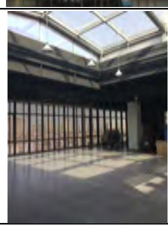
H5			Skylight Lighting	No	
H6			Skylight Lighting	No	
H7			Skylight Lighting	No	
H8			Skylight Lighting	No	
H9			Skylight Lighting	No	

Table 2 Diagram and Information of Library Sample

Sample NO.	Spatial Diagram		Spatial Interface		Picture
	Plane	Profile	Lighting Form	Sunshade	
L1			Skylight	Yes	
L2			Skylight	Yes	
L3			Skylight	Yes	

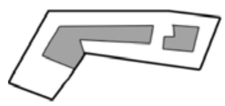
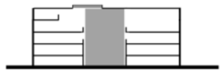
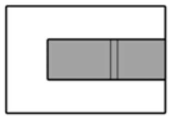
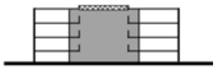
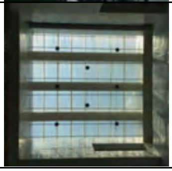
L4			Skylight and Sidelight	No	
L5			Skylight and Sidelight	Yes	

Table 3 Diagram and Information of Shopping Center Sample

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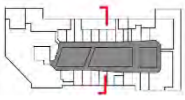
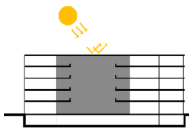
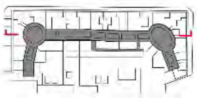
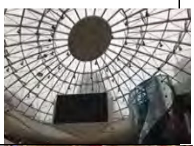
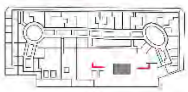
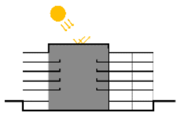
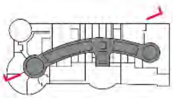
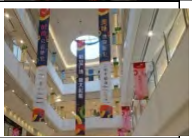
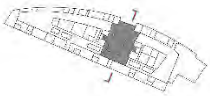
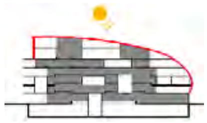
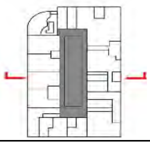
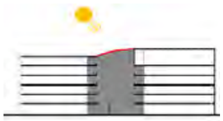
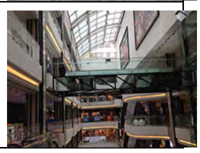
S1			No Natural Lighting	Yes	
S2			Skylight	Yes	
S3			Skylight	Yes	
S4			Skylight	No	
S5			Skylight	Yes	
S6			Skylight and Sidelight	Yes	

Measured Data

In case of field research, collect the data specifically for twice daily at 10 a.m. and 2:00 p.m. respectively in winter.

Hotel:

Serial NO.	Thermal Environment			Winter Average Illumination
	Air Temperature		Humidity (medial humidity)	
	Maximum Temperature	Minimum Temperature		
H1	22.5	20.2	18	1564
H2	26.5	23.2	＜15	1240

H3	23.5	20.0	＜15	839
H4	23.8	22.8	＜15	46
H5	25.6	16.2	22	200
H6	26.3	21.9	＜15	274
H7	23.2	20.0	26	1564
H8	26.5	21.4	＜15	1240
H9	23.9	20.8	＜15	839

In winter, most of the low temperatures are in the comfortable range, and the high temperatures are generally higher; the humidity is seriously inadequate, with most below the instrument measured value, while in summer the humidity is in a more comfortable range Only one atrium cannot meet the standard requirements of illumination, and other atriums can meet the standard in winter.

Library

Serial NO.	Thermal Environment			Winter Average Illumination
	Air Temperature		Humidity (medial humidity)	
	Maximum Temperature	Minimum Temperature		
L1	22.6	19.36	<15	1400
L2	22.01	15.05	<15	1500
L3	27.5	21.4	<15	1500
L4	29.01	17.33	<15	580
L5	27.76	19.3	<15	280

The air temperature distribution is uneven: there are overheating phenomena for part of the survey samples, and also there is the situation that the temperature is below the standard requirement, which has the greater impact on comfort level. All the air humidity in winter is below the minimum measured value.

In terms of illumination, only one sample has the too low illumination, while the data of others are in the range of comfort level with slight fluctuation.

Shopping Center:

Serial NO.	Thermal Environment			Winter Average Illumination
	Air Temperature		Humidity (medial humidity)	
	Maximum Temperature	Minimum Temperature		
S1	24.53	18.23	＜15	437
S2	22.84	15.85	22.7	1018
S3	25.11	18.72	18.8	328
S4	24.25	14.98	＜15	485
S5	19.04	24.10	＜15	648
S6	18.26	25.94	＜15	649

In winter, the air temperature distribution interval is larger, and the lowest temperature is below the minimum of standard interval, and the high temperature is higher than the maximum of standard range.Only two centers' air humidity in winter can be read.

Calculation and Acknowledgement

Air Temperature

The average air temperature of atrium space of the public buildings in cold areas is 22°C, which is in a more comfortable and reasonable interval. Among them, the average air temperature of the atrium space in the shopping centers is the lowest at 20.6°C; the average air temperature of the atrium space in libraries is the highest at 22.7°C.

In terms of the hotels, the situation that the temperature is higher than the standard maximum occurs in winter. The too high temperature in winter will increase the heating energy consumption of the buildings, so it's suggested to do appropriate adjustment.

As to the libraries, the air temperature in winter fluctuates greatly, which needs to be adjusted appropriately.

With regard to the shopping centers, the air temperature fluctuates greatly in winter.

Air Humidity

In cold areas, the medial humidity of the atrium space in public buildings is very low, and most of the humidity of the studied atriums is less than 15% of the minimum measured value. Among the 41 studied atriums, only the exact value of 8 atriums can be read and the average humidity is only 22.9%.

Illumination

In cold areas, the average illumination of the atrium space in public buildings is 1279lux in winter. Although 1279lux is a more comfortable illumination environment, its distribution is not even. Among the 41 studied atrium spaces, the illumination of four spaces is less than 300lux, that of five spaces is more than 2000lux, and the illumination of these atrium spaces is beyond the comfortable range.

Acknowledgements

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Daylight and Thermal Performance of Office Buildings in Ankara

Ece Durmaz[1] and Simos Yannas[2]

[1] Sustainable Environmental Design, Architectural Association Graduate School, London, UK, ecedurmaz.92@gmail.com
[2] Sustainable Environmental Design, Architectural Association Graduate School, London, UK, simos@aaschool.ac.uk.com

Abstract: With little regulation over energy consumption and a climate of cold winters and warm summers, the lack of benchmarks and built exemplars is a serious barrier to the development of an environmentally responsible architecture in Ankara, Turkey. The paper focuses on office buildings and draws upon the findings of recently completed research based on computational studies, using Radiance for daylighting and Energy Plus for thermal simulations, to explore the potential of passive design strategies taking account of orientation, external obstructions, solar protection and operational schedules including ventilation strategies.

Keywords: Thermal Performance, Daylight Performance, Ventilation Strategy, Office Building, Ankara

Introduction

According to national statistics some 470 office buildings were given building permits in the Turkish capital of Ankara in 2015 (TurkStat, 2016). Considering that the building sector is one of the largest energy consumers, it is crucial to follow-up current and future trends in occupancy and appliance use and how these affect internal heat gains and energy demand. There has been little research in Turkey on this topic especially in response to climate change. Johnston et. al (2011) described two likely future scenarios; one, where developments in technology would reduce the loads represented by appliances and artificial lighting (energy conscious scenario), and another where more and larger appliances (multiple monitors, media walls, etc.) would cause a massive increase in energy use (techno explosion scenario). The present paper summarises recent research (Durmaz, 2016) that looked at both of these scenarios as well as drawing comparisons with historical weather data and current operation of office buildings in Ankara.

Climate

Ankara is located in the central Anatolia region at latitude of $39^{o}56'$N and longitude $32^{o}52'$ E. Owing to its inland location winter months are cold and snowy, summers are hot and dry. Peak daily maximum temperatures can rise to 33^{o}C in summer with minima as low as -20^{o}C in winter (Fig. 1). Predictions for the year 2050 suggest an average increase of some 2^{o}C compared to recent historical data. Thus, future overheating problems should be considered while coping with the low winter temperatures. The high diurnal temperature fluctuations provide good potential for night-time cooling during summer. The adaptive thermal comfort band was calculated according to EN 15251 for Building Category II under present and future scenarios.

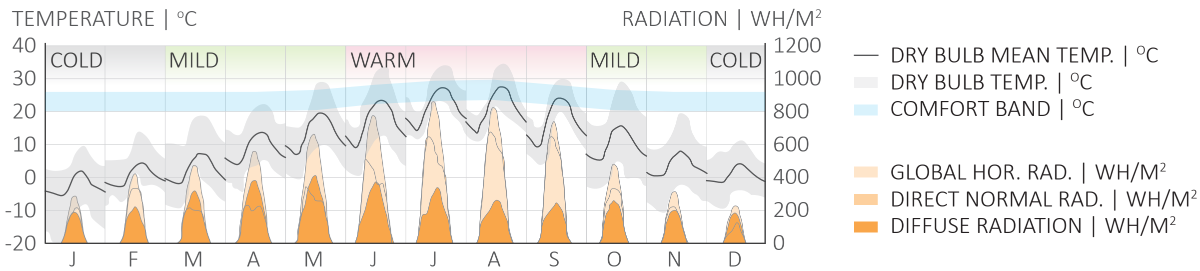

Fig1. Monthly diurnal averages for Ankara and adaptive comfort band according to EN15251 - Category II
Source: Meteonorm 7

Analytic Work

Daylight Analysis – Part 1: Solar Protection Strategies

Daylight simulations were performed with Radiance using the Ladybug and Honeybee user interfaces. A room of depth 6.0m and floor-to-ceiling height 3.2m was used throughout (Fig. 2). The periods selected for study include the most problematic times for each window orientation. The different solar protection devices considered by the study were tested under both overcast and sunny sky conditions. The simulation parameters are listed in Table 1. Figure 3 shows details of the solar protection devices that were assessed. For south-facing openings an overhang of 1.5m was assumed in conjunction with translucent or opaque horizontal blades. For east-facing openings, horizontal foldable panel and vertical shading devices were modelled. For west and north orientations, variants of vertical devices were assessed. The figure summarises the results highlighting the best shading strategy for each orientation. The simulation results showed that all orientations except for north require solar protection on openings to control illumination levels (Fig. 3). Translucent shading devices perform better than opaque elements and can eliminate the need for artificial lighting during daytime even when the shading devices are in place. As can be seen in Figure 3, translucent vertical shading and horizontal foldable elements performed similarly on east-facing openings. The horizontal foldable panel has the advantage that it does not impair the view. The north facade required internal roller due to over illumination next to the window.

Table1. Daylight Simulation Parameters

GENERAL	
AREA	135 m²
CLEAR HEIGHT	3.2 m
WINDOW TO WALL RATIO (WWR)	50% (Sill height: 80cm)
OCCUPANCY HOURS	09:00- 18:00
CONTEXT	No
MEASUREMENT PLANE	80 cm above floor
COMFORT RANGE	300- 2000 lux

TRANSMITTANCE	
GLAZING	0.65
REFLECTANCE	
WALL	0.65
FLOOR	0.45
CEILING	0.85
FURNITURE	0.60

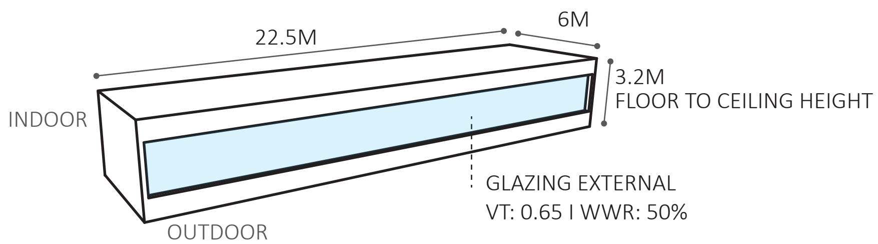

Fig2. Configuration of shoe-box model

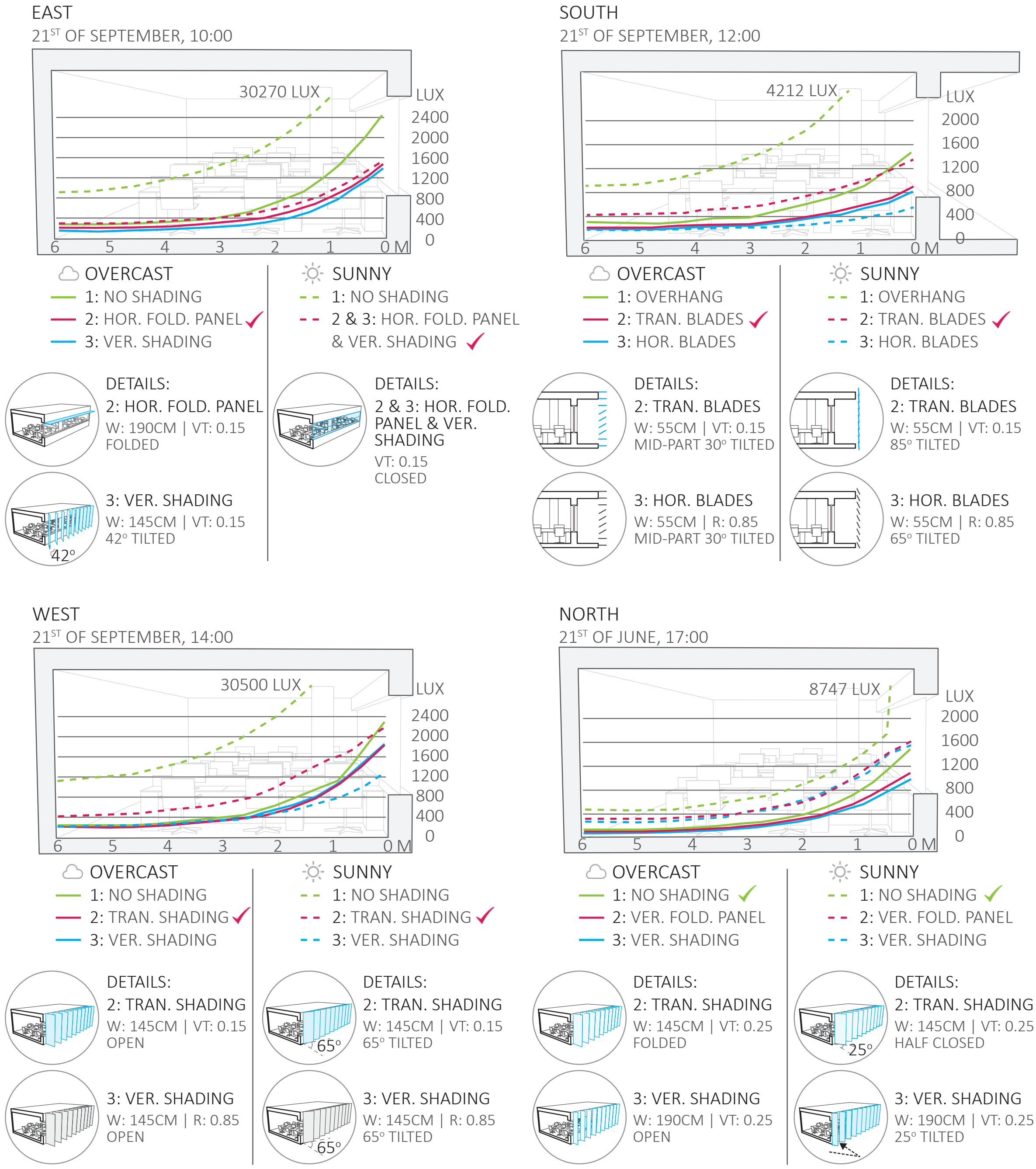

Fig3. Room sections showing daylight penetration with openings of different orientation and different shading strategies under sunny and overcast sky in Ankara
Source: Ladybug + Honeybee

Daylight Analysis – Part 2: Determining Depth

For these studies the plan depth was varied in the range of 8.0-10.0m with one of its side looking into a three-sided atrium (Figs. 4 and 5). On the street side, the obstruction angle was assumed to be of 30 degrees from window sill. Vertical shading devices (VT: 0.25) were assumed for atrium roof and vertical glazing in the west facing atrium. Orientation of the atrium was varied between north and west in further studies. For this, shading devices were only applied to atrium roof and north facade left unprotected. On the atrium side of the new shoe-box, glazing was assumed to have a visible light transmittance of 0.85. Daylight factors (DF), the useful daylight illuminance (UDI), the daylight autonomy (DA) and glare risk were calculated to assess daylighting performance.

As expected, Fig. 6 shows that obstruction from buildings across the street results in lower DF values in all cases. With daylighting incoming from two sides, the CIBSE (1999) minimum requirement of 2% daylight factor was achieved for south, east and west oriented offices even when the plan depth was extended to 10m depth. A wide circulation zone was positioned near the center of the room with the workstations placed closer to the facades. For rooms with north-facing openings the 8.0m depth gave better results.

UDI predictions are summarized in Figure 6. Low UDI values near windows are an indication of over-illumination that may cause glare. For this study workstations were assumed to be positioned at a distance of 0.5m from the window for the south-facing cases, Fig. 6. This was increased to 1.0m for east and west facing offices. The UDI pattern on the west-facing case was not homogenous within 1.0m setback due to the nature of the vertical shading devices. On north-facing cases workstations were positioned at a distance of 1.4m from the facade.

The Daylight Glare Probability (DGP) was found to be below 0.35, corresponding to imperceptible glare. A higher prediction of 0.43 was obtained for west-facing openings fitted with vertical shading devices under overcast sky. This problem can be eliminated by tilting the vertical shading devices.

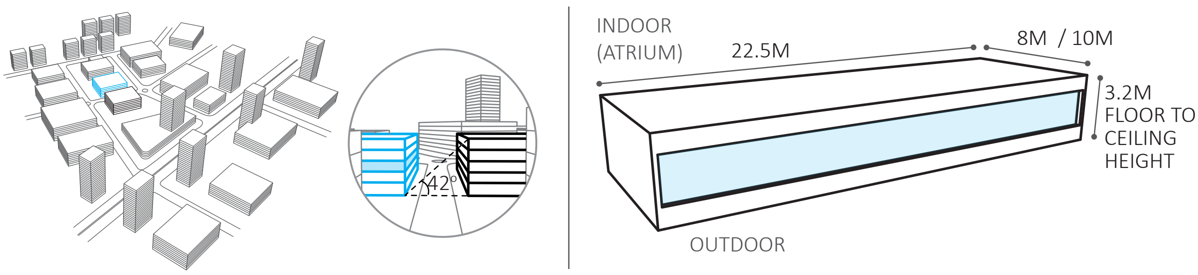

Fig4. Hypothetical context and dimensions of new shoe-box model

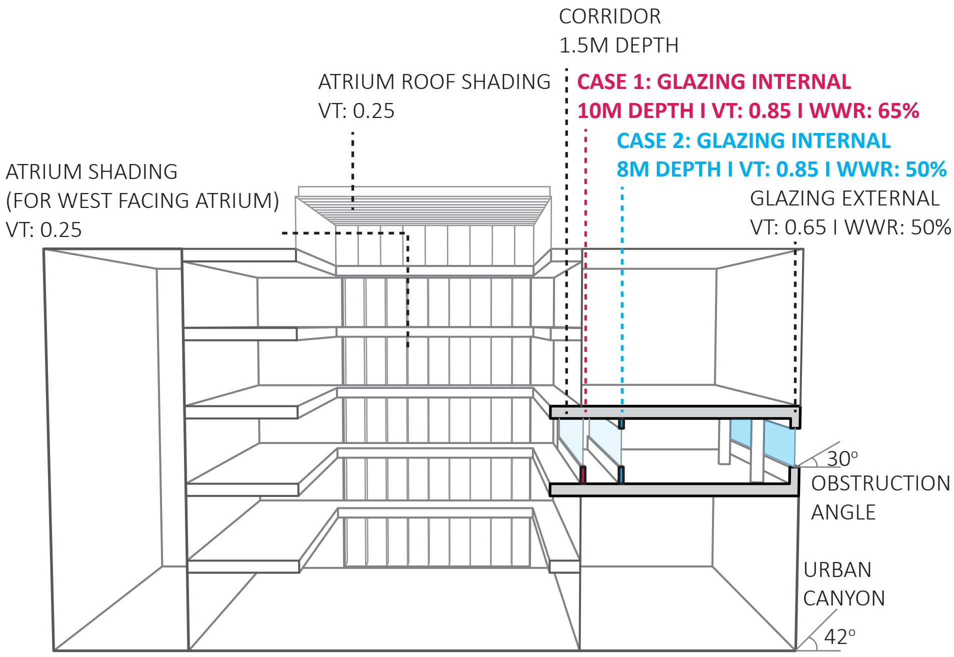

Fig5. Configuration of atrium and new shoe-box model

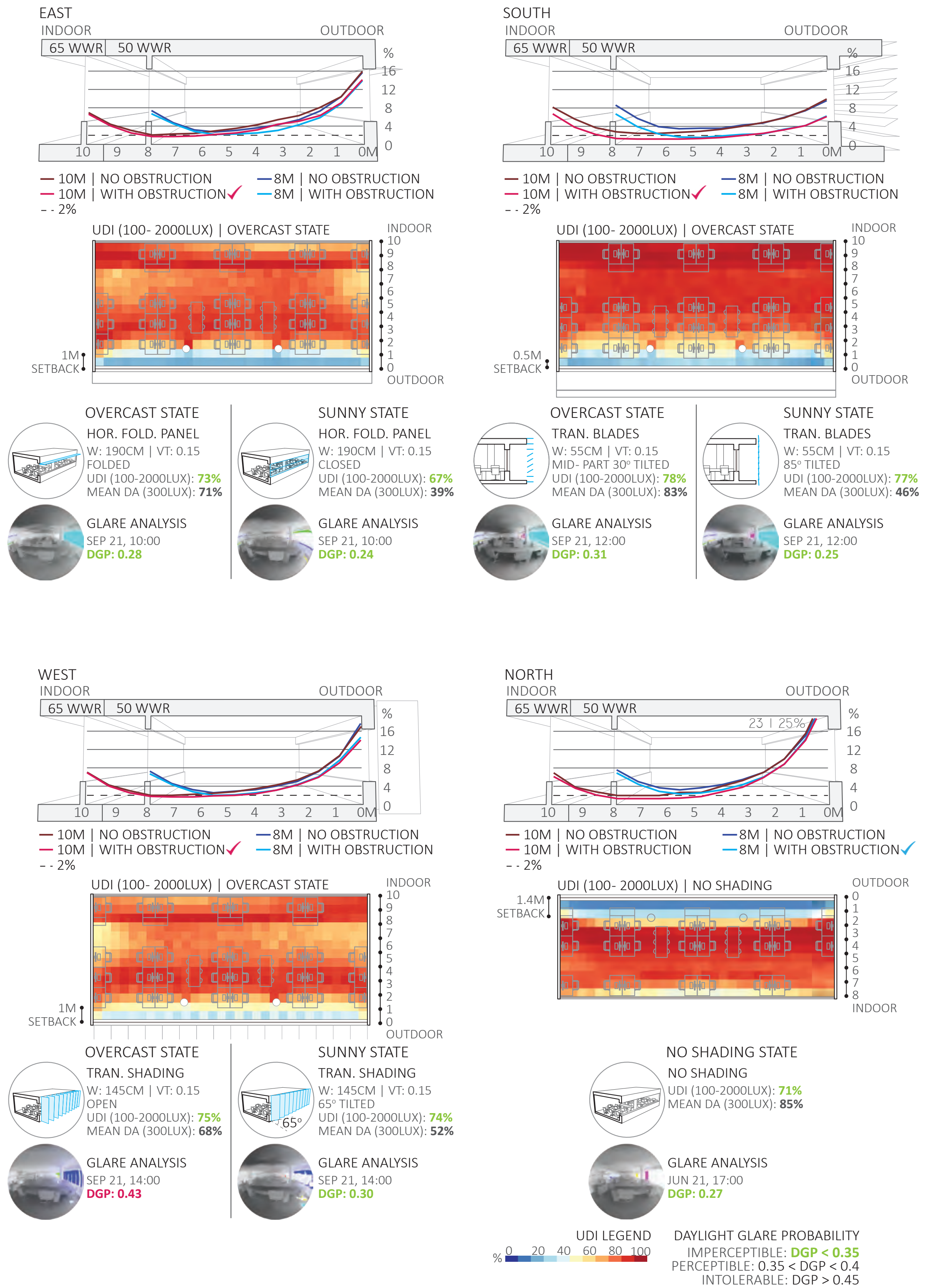

Fig6. DF plots (top), UDI (middle) and DGP (bottom)
Source: Ladybug + Honeybee

Thermal Analysis

Thermal simulations were undertaken with Energy Plus using the Open Studio plugin for Google SketchUp. The building model used was that for the "Daylight Simulations - Part 2". Key input data for the simulations are listed in Table 2 and Figure 7. Case A is based on the minimum standards of the TS825 Regulation (2008) for Region III. Case B represents typical construction in Ankara. Case C stands for best practice. A number of variants and operational conditions were studied and the results are summarized in Figure 8. Space heating and cooling loads were calculated for set points of 20°C and 26°C respectively. The simulations showed that differences in external obstruction did not have a significant impact on cooling loads owing to high summer sun angles. However, on East-West facing variants, the urban canyon had a significant effect in reducing cooling loads. Space heating loads increased, but by no more than 5 kWh/m² in all cases. Application of solar protection reduced cooling loads significantly, especially for Case C. Application of night shutters from November to mid-April improved performance in all cases. The efficacy of the night shutters was found to be directly related with the airtightness of the facade. The effect of higher air exchange rates, applied from May to October, varied.

Table2. General inputs and 3 envelopes defined for thermal simulations

GENERAL INPUTS	
AREA	225 m² (22.5 x 10m)
VOLUME	720 m³
OCCUPIED HOURS	09:00- 18:00 weekdays only
OCCUPANCY DENSITY	7.2 m²/person
LIGHTING POWER DENSITY	7 W/m²
EQUIPMENT POWER DENSITY	12 W/m²

	CASE A	CASE B	CASE C
INFILTRATION	0.75 ACH	0.5 ACH	0.3 ACH
FRESH AIR REQUIREMENT	1.03 ACH	1.03 ACH	1.03 ACH
WWR	75%	50%	50%
EXT. WALL U VALUE	0.5 W/m²K	0.5 W/m²K	0.17 W/m²K
GLAZING U VALUE	2.5 W/m²K	1.55 W/m²K	1.55 W/m²K

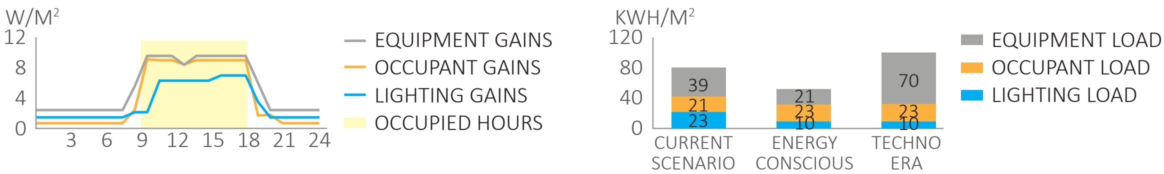

Fig7. Internal heat gain profiles for typical weekdays at present (left) and internal loads under current and future scenarios (right)

Space heating and cooling setpoints were re-adjusted for naturally ventilated cases in compliance with the EN 15251 (2007) adaptive thermal comfort band. For Case 4.3C, the cooling loads were reduced by up to 92% on the south-facing variants, Fig. 7. The south-facing offices were found to be free-running for 72% of the occupied time, Fig. 9. For other orientations, the free-running periods for Case C were 65%, 57% and 63% for east, west and north, respectively.

Cross ventilation and night-time cooling (Case 4.3) resulted in the best performance for all orientations. This variant was taken as a base case for the mitigation of climate change effects and for future trends in office design. Two future scenarios, Energy Conscious (5.1: EC) and Techno Era (5.2: TE) were tested (Fig. 10). South-facing Case C was found to perform best with 684 hours out of comfort under the EC scenario and 454 hours under TE, over a total of 2610 occupied hours, Fig. 10. Figure 11 shows simulation results for future variants of a south-facing office on typical summer and winter days. As can be seen in the figure, higher future outdoor air temperatures will make night-time ventilation necessary for summer cooling. Windows were assumed to be kept mostly closed during daytime. In winter, the rise in outdoor temperature may not be sufficient to compensate for the lower internal heat gains of the energy conscious scenario (Fig. 11 - Case 5.1). Hence, this will continue to require additional heating input for occupant thermal comfort. On the other hand, the techno explosion scenario (Fig. 11 - Case 5.2C) was shown to lead to overheating problems potentially throughout the year. The naturally ventilated period might need to be extended over the whole year or the building design specification should be reassessed.

Fig.8 Heating and cooling load consumptions for Case A (Green), Case B (Pink), Case C (Blue) envelopes
Source: OpenStudio & EnergyPlus

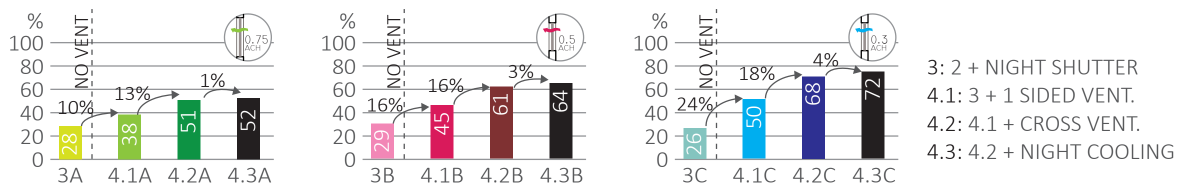

Fig.9 Percentage of occupied hours within comfort according to EN15251 Standard Category II for south facade
Left for Case A, middle for Case B and right for Case C
Source: EnergyPlus

DAY TIME OCCUPANCY:
80% -> 90%

LIGHTING LOAD:
7W/M² -> 4W/M²

EQUIPMENT LOAD:
12W/M²-> 6W/M²(5.1 EC)
12W/M²-> 22W/M²(5.2 TE)

FRESH AIR REQUIREMENT:
1.03 ACH -> 1.16 ACH

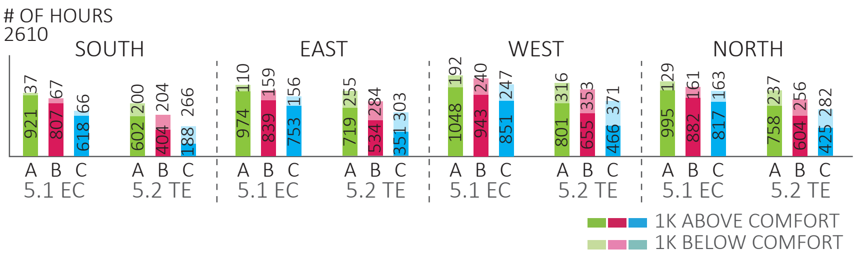

Fig10. New inputs (left), number of hours out of comfort for 1K according to EN15251 Standard (right)
Source: EnergyPlus

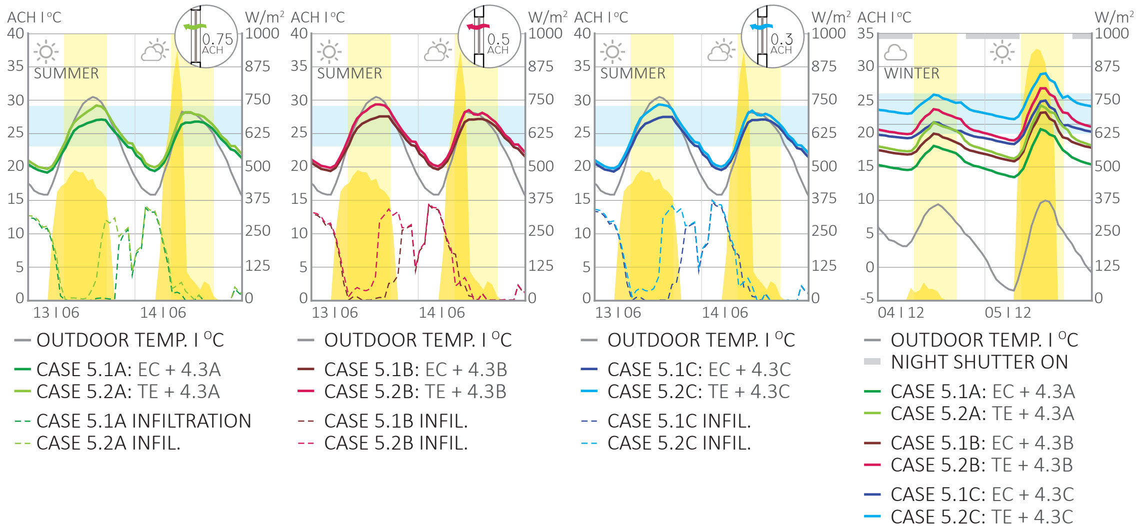

Fig11. Typical summer day (Case A, B, C respectively) and winter day (right) of a future south facing office
Source: EnergyPlus

Conclusions

The research summarized in this paper has shown the importance of window orientation in determining room depth and solar protection of workspaces in the climatic conditions of Ankara. Implementation of passive design measures can go a long way toward providing occupant thermal comfort for new office buildings. Conflicts between winter and summer performance tend to appear, but trade-offs can be found. The simulation studies showed that the atrium typology can provide better results for natural ventilation by exhausting warm air through the stack effect, and by creating a pleasant working environment for occupants. Occupant thermal comfort can be achieved for 72% of the time by the application of stack ventilation and night-time cooling on top of other passive strategies. Apart from the qualitative benefits, cooling loads can be reduced by up to 92% with a small penalty on heating loads.

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Shading Historical Commercial Streets in Hot Arid Areas: Questioning the Common Wisdom

Mohamed H. Elnabawi[1], Dr Neveen Hamza[2], and Dr Steven Dudek[2]

[1] Faculty of Engineering, MSA University, Cairo, Egypt, melnabawi@aucegypt.edu;
[2] School of Architecture, Planning and Landscape, Newcastle University, UK

Abstract: Vernacular shading systems dealt with solar radiation as the dominant components driving the heat balance equation for the hot, arid climate. Its positive climatic effectiveness as a traditional solution are herewith questioned. In order to improve the microclimate conditions at pedestrian level three different shading scenarios addressing the form and the opening of shading devices were simulated using CFD Fluent, based on two dependant variables including air temperature distribution and wind velocity. The findings show that typology and the opening locations are the paramount factors in providing a temperature reduction in the urban scale.

Keywords: CFD, historical settings, microclimates, shading

Introduction

According to Ibn-Khaldun (14th-century Arab historiographer and historian), one of the primary tasks of architecture is to create favourable microclimates where humans can live and work (Rotledge and Paul, 1987). Successive processes of trial and error over long periods of time have given satisfactory answers of architectural concepts and techniques concerning human comfort and the surrounding environment. In Islamic Cairo, a number of strategies attributed to the Arab vernacular architecture and urban design were developed over a long period of time, such as fabric compactness, the thermal mass of the street surroundings' buildings, shading, night ventilation and evaporative cooling. Accordingly, shade is still the main variable to be taken into consideration when aiming for the rehabilitation of traditional retail streets, and its implementation in locations characterized by outdoor hot discomfort conditions for pedestrians (Marques de Almeida, 2006)

In Fatimid Cairo, The topology and form of the shading structures were designed to protect the pedestrians beneath from the hot arid climate (figure 1). The structure was shaped and oriented to provide shade by screening solar radiation and the shading materials was chosen to absorb and transmit a minimum amount of solar heat into the space, and work in conjunction with thermal mass distributed within the enclosure to stabilise temperatures. The shading structure was also designed with a number of different openings so that the stratified air escapes at night and to allow the daylight to penetrate the space in order to reduce the need for artificial lighting.

The research attempts to investigate three different shading scenarios, in the Fatimid city of Cairo, addressing the form and the opening of shading devices by employing

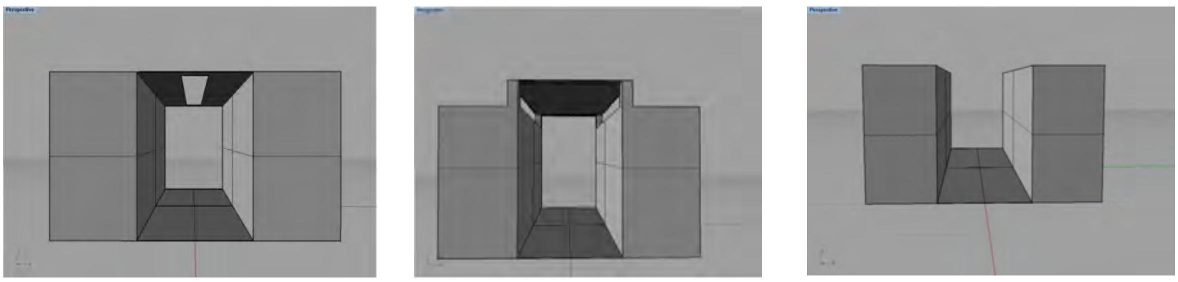
Computational Fluid Dynamics (CFD) to analyse two dependant variables including air temperature distribution and wind velocity.

Figure 1 the base case, as used by ancient town planners in the main commercial Street of the Fatimid city in order to provide both shading and daylight

Comparative study

The current research parametrically compares two shading configurations against a non shaded street in order to obtain the air temperature distribution and natural ventilation performance under each scenario. Each tested scenario, of the first two cases, consists of one specific geometrical change in the roof structure shapes and opening locations, while there was no roof for case number three as shown in Figure 1. The appropriate boundary conditions were set according to the same date used in the validation on 1st July 2012 as a representative for an extreme hot day (Elnabawi et al. 2013). All results were recorded at 1.4m above the ground level representing the average thermal affected pedestrians' height (Ali-Toudert and Mayer, 2007).

As shown in Figure 2, the aspect ratio (H/W) was the same for all the cases in being equal to 1.5, while the roof structure varied between the different cases. For instance, Case 1 was fully covered with one opening in the middle which is the existing configuration for the Fatimid city of Cairo, Case 2 had a roof 1m higher than the previous cases, with one opening on both sides and there was no roof for Case 3.



Case 1 (base case) Case 2 Case 3

Figure 2the alternative configurations for each case study with specific changes in the roof shape and opening locations

CFD simulation model

All the simulations were adjusted according to the best practice guidelines (BPG) scenario for developing existing urban configurations (Blocken, 2012), where the domain size, computational grid, boundary conditions, discretisation schemes, algorithms for pressure interpolation and pressure-velocity coupling are all well prescribed by BPG as stated in table 1.

Table 1Table 1Requirements for a consistent CFD simulation (AboHela et al., 2012).

Solution method	Second order schemes or above should be used for solving the algebraic equations
Residuals	in the range of 10^{-4} to 10^{-6}
Mesh	Multi-block structured mesh Carrying out sensitivity analysis with three levels of refinements where the ratio of cells for two consecutive grids should be at least 3.4
Turbulence model	Realizable k-ε turbulence model
Accuracy of studied buildings	Details of dimension equal to or more than 1m to be included
Domain dimensions	If H is the building height; lateral dimension = 2H+building width Flow direction dimension = 20H+building dimension in flow direction Vertical direction = 6H While maintaining a blockage ratio below 3%
Boundary conditions	Inflow: Horizontally homogenous log law ABL velocity profile _velocity inlet Bottom: No-slip wall with standard wall functions Top and side: symmetry Outflow: pressure outlet

Computational domain dimension and ABL profile

One of the main parameters affecting the reliability of the CFD simulation results is the horizontal homogeneity of the Atmospheric Boundary Layer (ABL) profile, which means the absence of streamwise gradients in the vertical profiles of the mean wind speed and turbulence quantities. This flow type occurs when the vertical mean wind speed and turbulence profiles are in equilibrium with the roughness characteristics of the ground surface. Fulfilling this requirement, first the model was placed in a computational domain with dimensions 147m x 85m x 45m as X, Y and Z (length, width and height), respectively. Then the user defined function (UDF) was used to specify the inlet boundary conditions satisfying equations (1), (2) and (3) for the velocity (u), turbulent kinetic energy (k) and turbulent dissipation rate (ε) respectively as mentioned by Richards and Hoxey (1993).

$$U = \frac{u^*}{k} ln \left(\frac{z+z_0}{z_0}\right) \quad \text{(Eq. 1)}$$

$$K = \frac{{u^*}^2}{\sqrt{C_u}} \quad \text{(Eq. 2)}$$

$$\varepsilon = \frac{{u^*}^3}{k(z+z_0)} \quad \text{(Eq. 3)}$$

Where (u^*)is the friction velocity(m/s), (k) is the von Kármán constant (= 0.40 or 0.42), (C_u) is the turbulence model constant, (z) is the height (m) and (z_0)is the aerodynamic roughness length (m), which is 0.5m or 1.0m depending on the wind direction. It is determined based on the updated Davenport roughness classification (Wieringa, 1992).

The bottom boundary condition was assigned as a rough wall and standard wall functions were used; the roughness height (ks) and roughness constant (Cs) were determined according to the relationship between ks, Cs as derived by Blocken et al. (2007b) satisfying equation (4) while the roughness length differs according to the nature of the terrain which is according to the case study equal 2.0 as described according to Davenport et al. (2000) for rough country as City centres with mixture of low-rise and high-rise buildings.

$$k_s = \frac{9.793\, z_0}{C_s} \qquad \text{(Eq. 4)}$$

The applied boundary conditions comprised of an inlet velocity of 3.5 m/s approaching from the north direction and inlet air temperature of 35^{o}C. The boundary conditions were assigned as symmetry conditions for all the sides and top boundary conditions, while the pressure outlet was imposed for the outlet boundary. The CFD simulations were then performed using the commercial CFD code Fluent 13.0 and the 3D steady RANS equations. Closure is provided by the realizable k-ε turbulence model (Shah et al., 1997). The choice for this turbulence model is based on the recommendations by Franke et al. (2004) and on earlier successful validation studies for pedestrian-level wind conditions (Blocken et al., 2007a, 2008b). Pressure velocity-coupling is taken care of by the SIMPLE algorithm. Pressure interpolation is second-order, and second-order discretisation schemes were used for both the convection terms and viscous terms of the governing equations (Blocken et al., 2012). The iterations were terminated when the scaled residuals did not show any further reduction with an increasing number of iterations. Horizontal homogeneity for the velocity (u), turbulent kinetic energy (k) and turbulent dissipation rate (ε) profiles were achieved throughout the computational domain. The profile was written from the outlet to be used as the inlet profile for all the simulations in the research.

The CFD model validation

According to the best practice guideline (BPG), the study was developed in an existing urban configuration with the availability of on-site field measurement. Therefore, the simulated CFD output was validated against the experimental measurement for the existing case. The results of the validation are presented within the graph as shown in Figure 3, and the simulated air temperature is compared with the in-situ air temperature measurements taken at three-hour intervals starting from 3:00 until 24:00 on 1st July 2012. It can be observed that the simulation results show a consistent trend with the observed ones and that the temperature differences are within 0.8°C to 1.2°C.

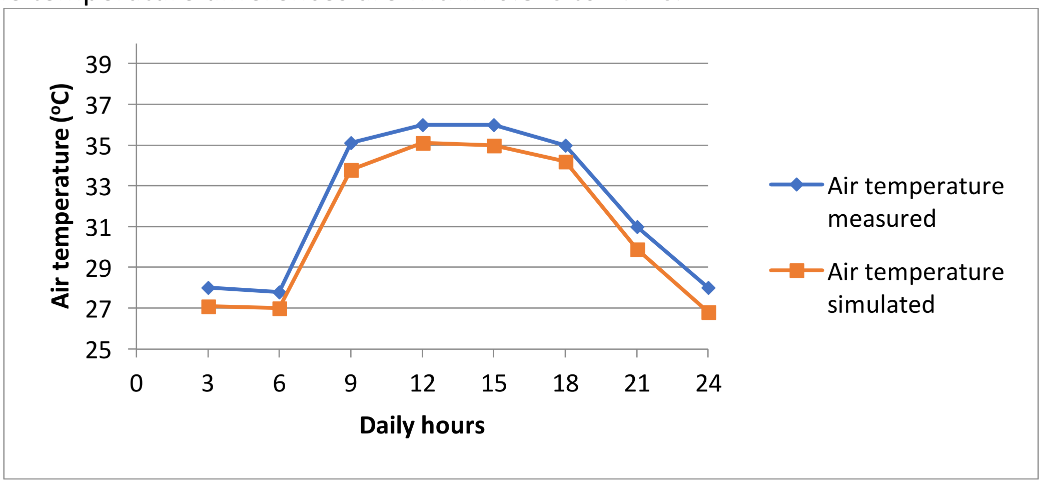


Figure 3 Comparison between the air temperature measured and the CFD output for the existing case on 1st July at pedestrian height of 1.4m

CFD simulations: comparative results

Comparison of the vertical profiles of the mean wind velocity

In order to examine the effect of wind speed at the pedestrian level, the vertical profiles of the mean wind velocity were measured at a point on the centre line of the street across the prevailing wind direction with a reference wind speed equal to 3m/s at U10 (at10m height) based on field measurements. Figure 4 shows the vertical profiles of all the cases from 0m at the ground level to 7m at the roof level. All cases may have had a similar profile until they started getting closer to the roof and the openings when the vertical profiles started to vary.

All three cases showed a consistent increase in air velocity with height but varied at roof level. Case 3 (without a roof) kept on the increasing trend of its vertical profile. In case 1, the centre roof opening assisted the wind to rise smoothly without much slowing down of its speed (almost 0.05m/sec velocity reduction). On contrary to case 2, where there was no opening in the roof centre, the wind velocity had to slow down and was released through the two side openings instead where the wind velocity reached its maximum, at 2.1m/sec, before it declined by reaching roof level recording 0.70m/second. This indicates that roof structure and different openings significantly affect the wind profiles beneath. The result is consistent with a previous study by Ng et al.(2011), which stated that the wind environment at the pedestrian level is not affected by building height but is significantly influenced by urban geometry in the pedestrian level.

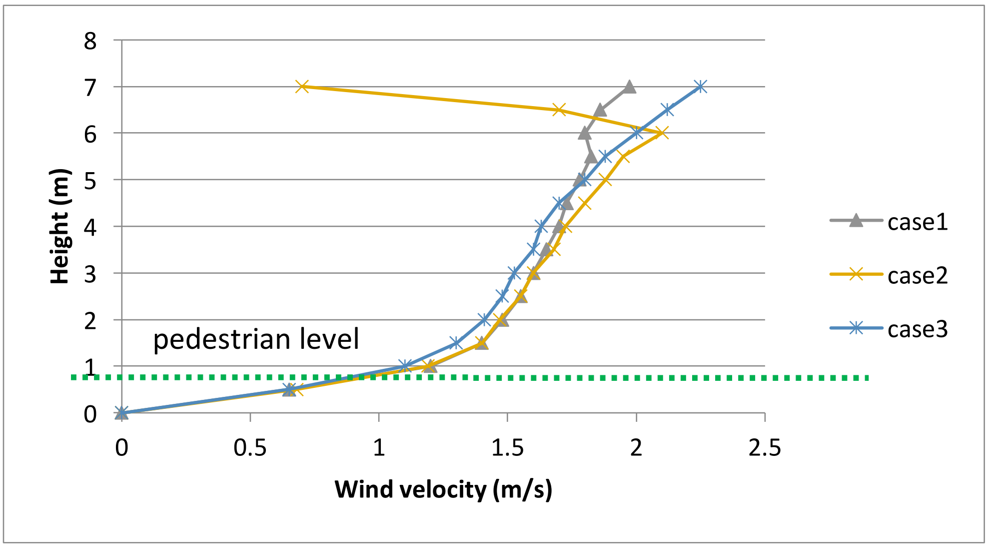
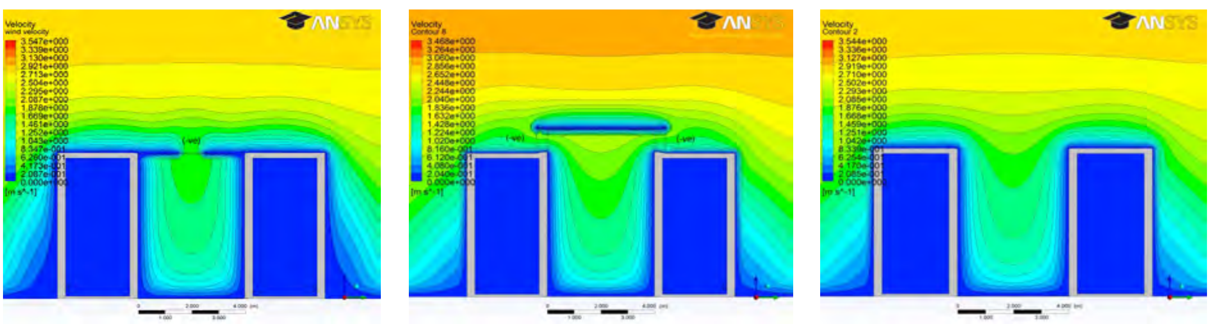


Figure 4 the vertical profiles of the mean wind velocities from the CFD simulation located at the centre line of the street (from 0m on the ground level to 7m on the roof level)



Case 1 (base case) Case 2 Case 3

Figure 5 the vertical wind speed contours at the centre line of the model

Comparison of air temperature distribution

The vertical profiles of the mean air temperature were measured at a point on the centre line of the street across the prevailing wind direction with a reference air temperature at the inlet equal to 35°C, as conducted from the field measurement. As illustrated in Figure 6, the air temperature vertical profiles were plotted for all the cases from 0m to 7m above the ground level.

All cases started between 32.4°C to 33.4°C at level zero as the surface temperature, which is lower than the inlet temperature due to the shading effect. Once the vertical profiles reached the pedestrian level (1.4m) above the ground level, case 3 recorded the highest air temperature followed by 1 and 2, all with minimal difference less than (0.2°C). The same four cases had the same trend of the vertical profile till reaching the roof level when case 2 faced a slight increase in air temperature directly under the roof before decreasing again at the side opening level. Therefore, it can be concluded that case 2 represented the best performance for having the lowest air temperature at the pedestrian levels between (1m to 2m above the ground level), as it kept 0.4°C difference with case 3 and 0.2°C difference with the base case 1. The air temperature distribution was directly proportional to level height: the higher the level, the higher the air temperature till the vertical profile meets the side openings when the air temperature suddenly increased due to the direct contact with the external air temperature at 35°C. This migration of warm air to the top of the enclosure offers potentially more comfortable conditions resulting from cooler air collecting at ground level in the inhabited zone. Moreover, the results indicated a negative correlation between the air temperature distribution underneath the different roof shapes and the ambient wind speed, as the wind speed increased about 1.4m and there was a rapid drop in temperature. This effect of wind velocity has been reported by numerous studies (Ng et al., 2008; Yuan and Ng, 2012), including Cheng et al. (2011), who reported that a 1.0m/s to 0.3m/s decrease in the wind speed is equal to a 1.9°C temperature increase, and Memon et al. (2010), who stated that air temperatures rose as high as 1.3K when ambient wind speed decreased from 4 m/s to 0.5 m/s.

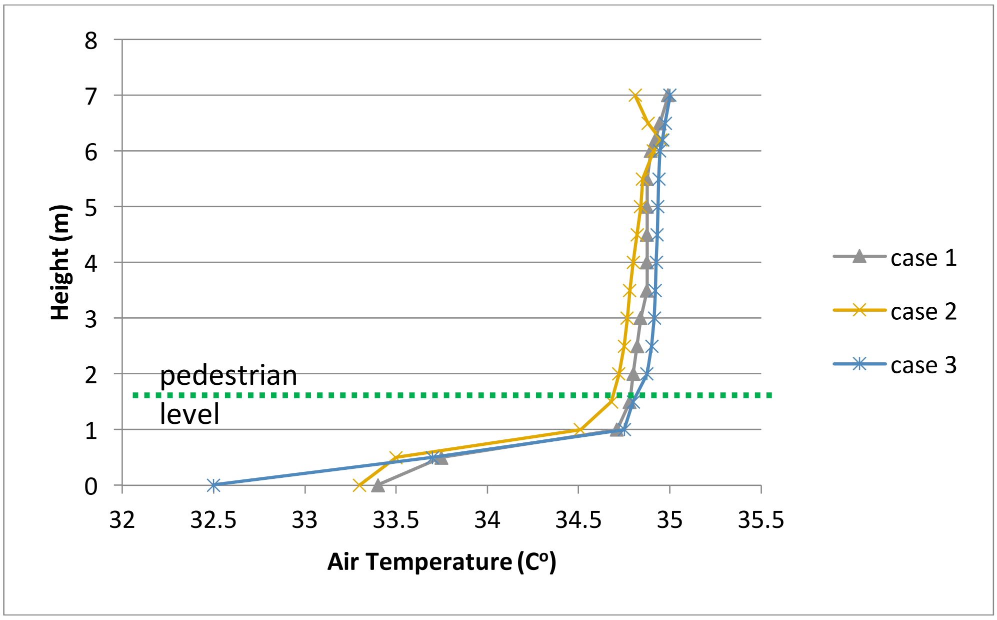


Figure 6 the simulated vertical profiles of the air temperature located at the centre line of the street (from 0m on the ground level to 7m on the top roof level)

Conclusion

As stated by numerous researchers, (Ali-Toudert and Mayer, 2006; Pearlmutter et al., 2007; Middel et al., 2014), the shading is the dominant factor driving the heat balance equation in the hot, arid regions. shading can provide a favourable reduction of the air temperature underneath up to 2.5^{o}C (Elnabawi, 2016) and it can improve the ambient air temperature by up to 15% based on a study conducted by Arizona State University in Phoenix, which is classified as a hot, arid climate (Love, 2009). However, during the night time the effect of the high shading patterns was largely reversed, which impeded the long wave radiant heat loss to sky due to the constricted SVF. According to Oke (1981) and Barring et al. (1985), the low sky view factor delays the cooling surface during clear calm nights where the heat released from the canyon materials is trapped in the canyon air volume (Svensson, 2004). In Japan, Kakon and Nobuo (2009) reported that increasing SVF by 10% would decrease UHI by 0.3% at night time.

The findings show that the structures' typology is one of the paramount factors in providing a temperature reduction on the urban scale while the opening locations is responsible for facilitating the heat release to escape at the night-time, where the minimal modification between the two scenarios leads to a reduction of air temperature with almost 0.5^{o}C due to the change in the opening locations and numbers as it causes a higher air exchange rate underneath, which has a positive effect in decreasing the air temperature. Hence, a high level of shading is required in outdoor environments to increase thermal comfort and extend the continuity of the acceptable thermal conditions during the day (Ali-Toudert and Mayer, 2006; Makaremi et al., 2012; Middel et al., 2014). However, a quantitative based study was still required for more different shading patterns.

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Design to Thrive

The role of Passive Low Energy Design in Energy Labelling of Housing

John Martin Evans[1] and Silvia de Schiller[2]

[1, 2] Research Centre Habitat & Energy, Faculty of Architecture, Design and Urbanism, University of Buenos Aires, Argentina
[1.] evansjmartin@gmail.com
[2.] sdeschiller@gmail.com

Abstract: This paper presents studies developed for the new energy labelling of housing in the proposed Argentine IRAM Standard 11.900 showing the potential for reducing energy demand in the residential sector. The process identifies the role and importance of passive bioclimatic design as a vital component of the estimated energy demand. In this framework, the proposed energy standard for energy labelling of housing includes a classification for passive design strategies that contribute to reduced energy demand in the widely varying climatic regions of Argentina, from latitude 22° in the tropics to 55° S with a sub-Antarctic climate, and from the coast to the high Andes. The paper then explains the climatic analysis procedure compared with comfort conditions to detect bioclimatic indicators that identify general strategies and specific design resources. Based on the concepts of the Mahoney Tables, Givoni's bioclimatic chart and the Evans Comfort Triangles, the study includes additional design resources and criteria to evaluate projects at the design stage, providing a list of passive design resources while defining the thermal properties contributing to reduce energy demand in existing and new housing. An alternative method evaluates their effectiveness of design resources when the design process is complete using detailed energy simulation.

Keywords: Bioclimatic Design, Energy labelling, Climate analysis, Thermal comfort.

Introduction

This paper first analyses the energy intensity of different sectors of the economy over the last decade to show the poor performance of housing when compared with other sectors of final energy use. This factor has promoted the introduction of energy labelling for housing to measure and promote energy efficiency, including the thermal performance of the building and the efficiency of the installations, following the strategy adopted in Europe (BRE, 2014, EU, 2010).

The energy certification of housing in the proposed Argentine IRAM Standard 11.900 (2010) identifies the importance of passive bioclimatic design as a vital component of the estimated energy demand. This study presents a method for identifying passive design strategies that will achieve reduced energy demand in the widely varying climatic regions of Argentina, from latitude 22° in the tropics to 55° S, and from the coast to the high Andes, over 3000 m above sea level. The paper presents the sequence of climatic analysis and comparison with comfort conditions, to detect indicators of dryness, humidity and coldness. This leads to the identification of general strategies and specific design resources. The paper indicates complementary actions to verify the results.

Comparative Energy Intensity

The Argentine National Energy Statistics show the energy demand according to primary and secondary energy sources for each economic sector for the period 1965-2015 (MINEM, 2017). The analysis presented in this paper shows that the residential sector has the highest average annual increase in both relative and absolute terms over the last 50 years. It also has the worst tendency in energy efficiency in the last decade.

To estimate changes and tendencies of efficiency in different sectors, variation in energy intensity in each of them were estimated for the last decade (2006-2015). Figure 1 shows an index of the estimated energy intensity per sector compared with indirect indicators of the level of energy service, according to the following evaluation:

- **Gross Domestic Product**: The GDP per capita, at constant dollar value, is compared with energy use. After a decade, the GDP per capita has increased 127 %, with little change in the energy demand for all final uses. The generation of 1 dollar GDP in 2015 requires 47 % less energy than in 2016.
- **Automobiles and other light vehicles:** The number of registered units is compared with the final petrol and gas use in transport (gas is widely used in light vehicles). In 2015, each vehicle used on average 16 % less energy than in 2006.
- **Heavy vehicles, buses and lorries**: The number of vehicles is compared with the diesel fuel used. At the end of the decade, each vehicle uses on average 33 % less energy.
- **Non-residential buildings:** The number of employees in the service sector, excluding occupations that do not use buildings is compared with energy use in non-residential buildings. On average, the energy used by employee in this sector has not changed significantly over the decade.
- **Residential sector:** The number of houses is compared with energy demand. Each house has increased its energy demand by 25 % during the decade, though the number of occupants has declined, average house size is lower and the efficiency of equipment and installations, heaters, air-conditioners, lighting, fridges and freezers, etc., has increased significantly.

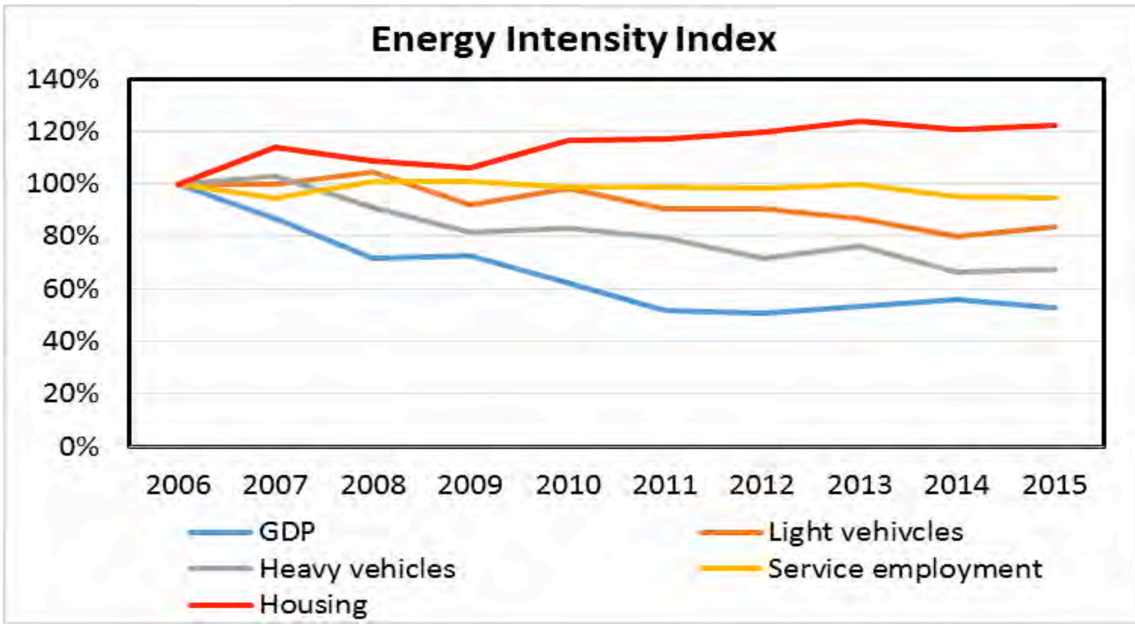

Figure 1. Index of energy intensity in different sectors according to final energy use, 2006-2015 (Authors estimates using data from MINEM (2017), INDEC (2017) and other sources.

The clear difference between increasing energy use in housing and stable or reduced energy use in other sectors is due to a number of factors: improved environmental quality with better thermal and lighting conditions, increased numbers and sizes of electrical goods, such as televisions, computers, wifi, cell phones, refrigerators, etc. However, most of the energy demand in the residential sector is for heating (de Schiller and Evans, 2015), and it is concluded that the declining thermal quality of buildings is a major factor.

Standards of energy labelling and performance

Energy standards for buildings were introduced in Argentina in 1970 to ensure minimum thermal performance of low cost housing (IRAM, 2009). These have been modified and adjusted over the years, although today's low cost housing standards continue to have similar thermal performance to the requirements of 40 years ago. Apart from local legislation in the Province of Buenos Aires (2007), the City of Buenos Aires (2017) and the Municipality of Rosario (2015), there is no obligatory thermal performance standard for building of the private sector. One of the difficulties of implementing improved thermal standards is the existing legal framework, as municipalities with limited technical capacity are responsible for developing and applying building codes, considering over 2000 different municipalities in Argentina, with 124 in the Province of Buenos Aires. Another difficulty is the wide range of conditions, from warm humid sub-tropical climates at latitude 22°, hot dry continental climates, cold and dry windy climate in Patagonia, with sub-Antarctic climates at latitude 55°, and cold climates in the high Andes at over 3000 metres.

Energy labelling is an effective measure to evaluate and improve energy efficiency, and Argentina has achieved considerable improvements in fridges, freezers and lamps, as a result of compulsory labelling and eventual prohibition of equipment with low efficiency. A standard for labelling of efficient windows, based on IRAM (2010), will be approved shortly. In 2007, a new standard for energy labelling of housing was approved (IRAM, 2007) but was not compulsory, so it had no practical effect on energy efficiency in buildings. Due to difficulties with increasing energy tariffs, high costs for exploration and extraction of hydrocarbons and growing energy imports, the present government is proposing a revised energy labelling standard. In addition to the estimated annual energy demand, the proposed new standard includes indicators of the components that contribute to energy efficiency: efficiency of heating, cooling, artificial lighting, and hot water systems, incorporation of renewable energy and bioclimatic design.

This paper describes the proposed procedure to evaluate the contribution of passive bioclimatic design indicators to energy efficiency. This is considered especially important in new buildings, as designers can use these indicators to identify bioclimatic design resources for each climatic region, before detailed energy performance calculations can be made. They also show possible but limited bioclimatic improvements in existing housing.

Figure 2 shows the structure of the proposed standard, the relation between different components of the standard and the importance of bioclimatic design strategies. Appropriate passive or bioclimatic design solutions will have a cumulative effect, reducing the energy demand for heating, cooling and artificial lighting, acting in combination with improved efficiency of the installations. They also increase the percentage contribution of renewable energies.

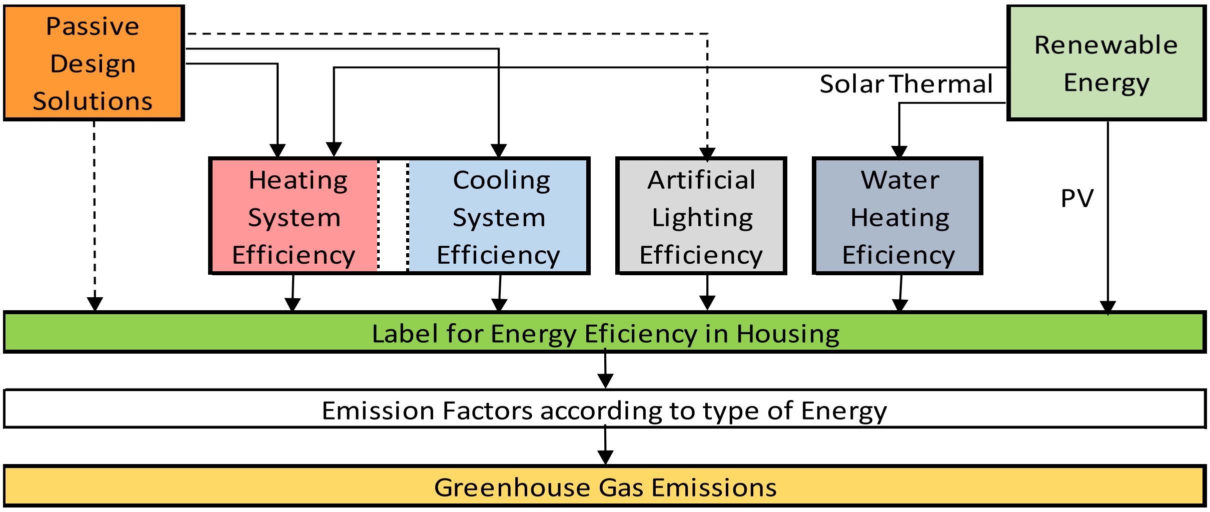

Figure 2. Structure and components of the proposed standard for energy efficiency in housing, IRAM 11900.

Procedure

The procedure aims to evaluate the contribution of bioclimatic design to energy efficiency in housing projects using a scale from 0 to 6. This complements a similar evaluation of the energy efficiency of heating, cooling, lighting and water heating installations as well as the possible contribution of renewable energy installations. The procedure consists of four stages starting from the design and construction components that can contribute to energy efficiency and finishing in the degree to which the design responds to the bioclimatic strategies required in a specific climate:

- **Ranking design and construction solutions:** 18 potential bioclimatic design and construction resources incorporated in the house design are evaluated according to performance alternative standards on a scale from 0 to 6, for example different levels of thermal transmittance, roof reflectivity or compactness of building form.
- **Integrating response to bioclimatic strategies:** Groups of these design resources are evaluated according to their response to each of the 6 bioclimatic strategies considered, with a weighting system to obtain a composite score using the same 0 to 6 point scale. These resources include energy conservation, solar protection, and response to cross ventilation.
- **Identifying the importance of each bioclimatic strategy:** Climate files of daily data for specific locations are analysed to detect the proportion of time that each design strategy is required.
- **Relating bioclimatic responses to the required strategies:** The final score is obtained according to the importance of the response to each bioclimatic design strategy that contributes to energy efficiency according to balance of bioclimatic requirements and the bioclimatic characteristics of each location.

Each of these steps is explained in the following sections. The relation between the design and construction solutions and the bioclimatic strategies is shown in Table 1. Initially 43 design and construction solutions were identified, but this number makes the application of these criteria difficult. So those solutions that had limited effect on overall energy efficiency were eliminated, for example the thermal performance of window frames. The number of bioclimatic design strategies was also reduced to 6 from the initial 16 defined for housing in the Climate Consultant (UCLA, 2017), or the 11 strategies proposed by Givoni (1980). For example, the humidification strategy recommended for very dry conditions was eliminated as the frequency of these conditions is very low in most locations in Argentina and the impact on energy efficiency is limited, although this strategy does contribute to comfort. As another example, wind protection in outdoor spaces was also eliminated as it has limited impact on energy demand in indoor spaces

Table 1. Relation between bioclimatic design strategies and design and construction resources.

		Bioclimatic design strategies						
N°	Bioclimatic resources, design and construction	Thermal insulation	Thermal inertia	Solar protection	Cross ventilation	Passive solar	Selective ventilation	Total
1	Thermal insulation roof	1	1	1		1		4
2	Thermal insulation walls	1	1			1		3
3	Thermal insulation glazing	1	1			1		3
4	Thermal insulation floors	1	1			1		3
5	Thermal inertia roofs		1			1	1	3
6	Thermal inertia walls		1			1	1	3
7	Thermal insulation floors		1			1	1	3
8	External colour roof			1				1
9	Window orientation, sun			1		1		2
10	Solar protection, glazing			1		1		2
11	Passive solar systems					1		1
12	Floor to cieling hieght	1					1	2
13	Contact, party walls & other dwellings	1						1
14	External solar shading			1		1		2
15	Glazing in roof	1		1		1		3
16	Compact form	1	1		1	1		4
17	Glazing as % of wall	1		1	1			3
18	Conditions for cross ventilation				1			1

Ranking architectural and construction solutions

In order to evaluate existing housing or projects at the design stage, possible alternatives of each of the bioclimatic design or construction solutions were identified, based on quality levels defined wherever possible in existing standards and qualified in a 6 point scale ranging from ‘deficient’ to ‘optimum’. The simplified definition of alternatives is designed to facilitate evaluation of both new and existing housing.

Table 2 shows an example for the thermal insulation solutions. The standard identifies these alternatives and the rating for each of the 18 design resources or solutions.

Table 2. Example of the rating for thermal insulation alternatives.

Rating	Criteria	Standard	Example: walls in Buenos Aires
0	Deficient	Not compliant IRAM 11605	K > 1,85
1.5	Minimum	IRAM 11605, Level C	1,85 < K < 1,0
3	Average	IRAM 11605, Level B	1,0 < K < 0,38
4.4	Excellent	IRAM 11.605, Level A	0,15 < K < 0,38
6	Optimum	Passive House standard	K < 0,15

Notes:

- K = Air to air thermal transmitance W/m^{2}K (U Value)
- IRAM Standard 11605 (1998) defines three levels of thermal transmittance values for walls and roofs according to the winter minimum design temperature and the maximum summer design temperature with average external reflectivity. (Roof colour is covered by different design solution (N° 8 in Table 1).
- Passive House Standard (PHS, 2017) indicates an optimum level although not an Argentine standard.

Integrating response to bioclimatic strategies:

There is a complex relation between bioclimatic strategies, and design and construction solutions, with many solutions contributing to more than one strategy, and all strategies are modified by two or more design and construction solutions. As Table 1 shows, 9 design and construction solutions contribute to energy conservation and to thermal inertia, while 13 are related to the effectiveness of passive solar systems. Solar protection and ventilation strategies also relate to various solutions. The aim of this section is to evaluate the partial contribution of each solution to bioclimatic strategies.

The standard proposes a weighting system to evaluate the impact of each solution in the response to each bioclimatic strategy. The weighting can depend on aspects of house design. For example the overall thermal inertia of the house depends on the thermal inertia of the building elements in contact with indoor air, and surface areas of each as well as compact form and the contributory effect of thermal insulation. Table 3 presents an example of the application of the weightings for thermal inertia. This includes weighting factors for the proportion of floor to wall surfaces for two story housing compared with one story housing. A spread-sheet has been prepared to facilitate the application of the weighting system using the selection of alternatives from pull-down lists.

Table 3. Example of the application of the weighting system to evaluate response to thermal inertia strategy.

Design solutions	Weight	Points	N° of Floors = 2	Weighted Points
Thermal inertia roof	Average	2,5	0,19	0,5
Inertia external walls	Average	2,5	0,19	0,5
Inertia internal walls	Heavy	5	0,19	1,0
Inertia ground floor	Very heavy	6	0,12	0,7
Inertia ceiling	Average	2,5	0,19	0,5
Thermal Inertia upper floor	Average	3	0,12	0,4
Points without weighting				3,5

Housing form	Compact 2 floors	0,4
Thermal insulation	Minimum, Level C	0
Total points with weighting	Average	**4**

Reference tables identify construction alternatives that correspond to thermal inertia levels, based on surface density in the construction layers in the 10 cm closes to the indoor surface of the component.

Identifying the importance of each bioclimatic strategy

For consistency, EPW data files are used for the analysis of climatic data, as these are also used in the detailed energy performance calculation. The 'climate evaluator' (UCLA, 2017) based in the bioclimatic chart (Givoni, 1980) was used initially to analyse the relative requirements of each strategy. It requires adjustments for the climate variations, comfort expectations and building technologies of Argentina. A revised chart was prepared using a spreadsheet to process the EPW files and obtain indicators of the bioclimatic requirements based on the number of hours with specified conditions, with the following adjusted criteria.

- The lower limit of the winter comfort zone is fixed at 18° as proposed by Givoni, rather than 20° C, considering an average indoor temperature.
- Passive solar systems are only indicated for daylight hours with solar radiation. Solar radiation is also favourable for energy savings when the temperatures are below 10° C.
- Thermal inertia is indicated when heavy construction can improve thermal comfort on days with high thermal swing, or when heat storage improves energy efficiency. The comfort triangles (Evans, 2003) are used to establish requirements for thermal inertia.

The climate data analysis shows the proportion of time that each strategy is required. In addition to the analysis based on the Climate Evaluator, two further analyses are included:

- Passive solar heating strategies only correspond to hours when the sun altitude is over 10°. Solar protection is also limited to the hours when the sun is above the horizon.
- The requirement for thermal inertia is based on the daily temperature swing, and the spreadsheet analysis of the EPW climate files also presents a graph of the Comfort Triangles (Evans, 2003) showing daily temperature swing on the vertical axis and average daily temperature on the horizontal axis.

Relating bioclimatic responses to the required strategies

The final stage is the adaption of the response to each strategy according to the importance of each strategy and the relative importance of each for energy conservation. The procedure is complex, reflecting the difficulty in evaluating the bioclimatic and passive thermal performance of housing in the wide range of climatic conditions found in Argentina. The final result is a score on the 0 to 6 point scale.

In parallel to the passive bioclimatic evaluation outlined in this paper, various studies are being developed to cover the different aspects of energy efficiency:

- The calculation method for evaluating energy efficiency is being developed for the standard, based on ISO Energy simulation standard.
- A pilot project for applying the draft standard is underway in the Province of Santa Fe to test the calculation method.
- A demonstration project for reducing energy demand in social housing will measure performance in 8 locations in new houses with different thermal envelopes, bioclimatic design resources, construction alternatives and renewable energy installations (de Schiller and Evans, 2016).

Conclusions

The paper presents the proposed procedure for evaluating the contribution of passive and bioclimatic design solutions to energy efficiency in housing. As well as integrating this key factor in an energy efficiency label, the procedure indicates favourable design solutions for the designer at an early project stage. As the objective is to evaluate projects, the procedure reverses the conventional bioclimatic design process which starts with climate analysis in relation to comfort requirements. Design and construction solutions are classified and compared with bioclimatic strategies and then scored according to their contribution to energy efficiency in a specific location. Although the procedure is complex to describe, the spreadsheet simplifies application with the selection of alternatives from pull-down lists. The procedure will be tested by comparison with measurements in housing and a new calculation method. It is anticipated that this will confirm the important contribution of passive bioclimatic design to energy efficiency in housing.

Acknowledgements

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Thermal Performance of a Thermal Performance of a Roof-Pond System Under Subtropical Conditions

Leandro Fernandes[1], Eduardo Krüger[1]

[1] Programa de Pós-Graduação em Tecnologia, Universidade Tecnológica Federal do Paraná, Curitiba, Brazil, fernandes.ufpr@gmail.com , ekruger@utfpr.edu.br

Abstract: Under subtropical conditions with mild winters, a roof pond-based passive system should ideally be designed to promote cooling and heating, according to different operation modes. This study aims to evaluate the thermal performance of roof pond configurations by means of experiments in test cells in Curitiba, Brazil (25.5°S, 49°W, 910 a.m.s.l.). Different modes of operation were tested in the warm and in the cold seasons of the year in respect of indoor temperatures. Configurations of the system encompassed: a) roof pond with indirect evaporative cooling function, shaded; b) roof pond with sealed water reservoir, naturally ventilated and shaded (for testing the effect of thermal mass with no evaporative function); c) roof pond, unshaded; d) selective solar exposure of the pond in winter, with venetian blinds during daytime and fully closed at night. Results show that, in summer, on a clear day, indoor temperature can be lowered by approximately 7°C relative to outdoors; in winter, the best configuration (selective solar exposure) yielded a rise of almost 12°C. Time lag and decrement factor were found to be significant only in summer with virtually no time-lag effects in winter, also with increased indoor swings when shading was not present.

Keywords: roof pond, evaporative cooling, thermal, passive heating.

Introduction

There are several possible configurations of passive evaporative cooling systems (Chan et al. 2010, Sharifi & Yamagata 2015), many of which have been reported in the literature during the last half-century such as roof ponds with or without moveable insulation, roof ponds with shading elements, natural draft cooling towers, among other systems. One of the most reported cooling systems consists of using roof ponds directly over the area to be cooled. The pond's water temperature will be close to the average wet-bulb temperature (WBT) and the ceiling, cooled by the pond, acts as a heat sink to the space below it. Such system can be permanently shaded, selectively shaded (during daytime only) or remain unshaded (open roof ponds) (Yannas et al. 2006).

Apart from providing indirect evaporative cooling, another way of thermally using a roof pond consists of sealed water containers with no need for replenishing. The evaporative cooling function is cancelled and the system runs based on the increased thermal mass of the water container. The Skytherm system (Hay and Yellott 1969) combines the use of closed water containers with moveable insulation for controlling heat gains or losses, depending on the season of the year. The effect is a pronounced stabilization of indoor air temperature. Givoni (1994) reports on the cooling performance of the "Atascadero House", in Atascadero, California which uses the Skytherm system and shows that ambient temperature fluctuation can be sharply reduced due to the combined use of stored water-filled plastic bags and insulating panels.

Winter applications of roof ponds are not as frequently reported in the area literature as in the case of roof pond-based cooling systems for summer conditions. The Skytherm system uses a reverse operation of the insulating panels in winter, covering the roof during the night to prevent heat losses and opening it during the day to absorb solar heat (Sharifi & Yamagata 2015). More complex systems can be used in combination with supporting storage heating systems, collection of solar-heated water from tiles and draining the pond at night. The most simple variant, yet not quite effective is to expose the roof pond continuously, in this case however with evaporative and radiant heat losses (Sharifi & Yamagata 2015). Using a glass cover on top of the pond could restrict such losses, turning it to a water-tight chamber.

The operation modes of a roof pond depend on a great extent on the user when automation is not an option. Thus, simplicity in operation is desirable. In this paper we analyse diverse modes of operation of a roof-pond passive system in respect of seasonal changes in ambient temperature patterns under the climatic conditions of a subtropical location. Tests have been carried with a same test cell and using the same instruments, so that inter-comparisons were made possible.

Materials and methods

Location

Curitiba (25.5°S, 49°W, 910 a.m.s.l.) is located in a tropical climate zone in a relatively high-altitude region of Brazil (Cfb/Koeppen). It often experiences unstable meteorological conditions with large daily and annual air temperature fluctuations. Average air temperature in summer is approximately 20°C, though average air temperature in winter is quite low for tropical standards, averaging 13°C in June/July. The evaporative cooling potential estimated for an existing system based on such strategy and applied to an experimental dwelling was considered to be significant (Gonzalez & Krüger 2015), responding with nearly 90% of the annual cooling demand in that location.

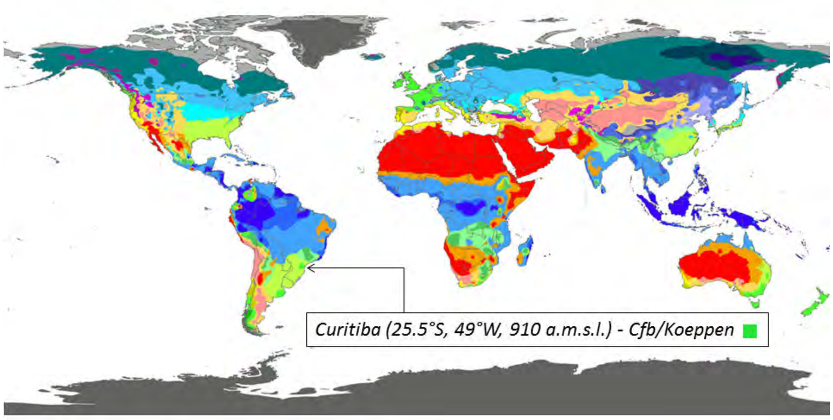


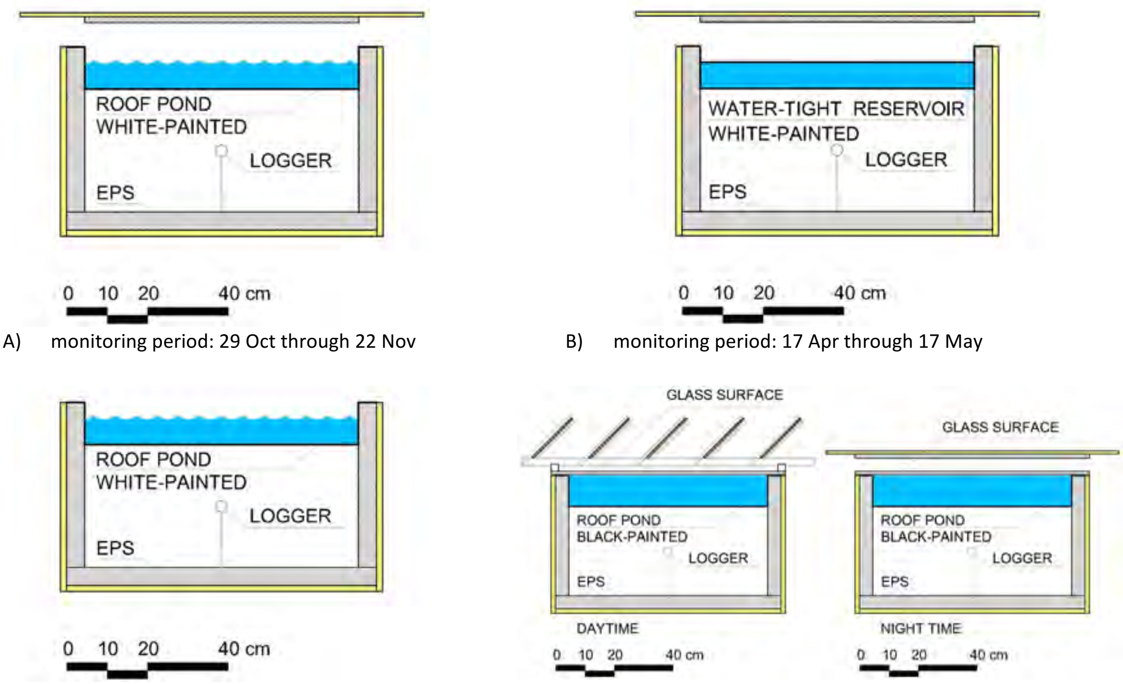
Figure 1: Location on Koeppen’s World Map with climate classifications

Experimental Setup

A small test cell (80×80×45cm) was used for testing different configurations of the roof pond. The test cell is made of lightweight, low-density wood panels, whitewashed and with an internal 4.5 cm thick layer of expanded polystyrene, which ensured a low U-value of 0.70 W⁄(m².K). The roof consists of a metallic water reservoir, white-painted with approximately 6cm of water. When shaded, an insulating wooden roof cover is used. Underneath it there is a 1.5 cm thick layer of EPS. Configurations of the system tested are the following:

a) roof pond with indirect evaporative cooling function, shaded and with a ventilated crawl space between the roof pond and the cover to enhance evaporative processes; the cover provides a small overhang and has measures 1.0×1.0m;
b) as in (a), but with water-tight reservoir, covered by the same metallic material as the reservoir's (for testing the effect of thermal mass though with no evaporative function);
c) roof pond, exposed and unshaded;
d) selective solar exposure of the pond in winter, with venetian blinds (with a tilt angle of 45°) used during daytime and fully closed at night; the pond is permanently covered by a glass surface to prevent convective heat losses and the reservoir is painted black and filled to the top (with water depth 10cm).

Figure 2 shows schematically the diverse configurations tested in this paper with corresponding periods of the year during which indoor temperature monitoring took place. Temperature data loggers were used both for monitoring indoor air temperatures and for recording ambient temperature, in 15-minute intervals.



A) monitoring period: 29 Oct through 22 Nov

B) monitoring period: 17 Apr through 17 May

C) monitoring period: 19 Jan through 21 Jan

D) monitoring period: 11 Sept through 13 Sept

Figure 2: Configurations tested and periods analysed

Results

Within each of the four monitoring periods, a day with clear-sky conditions was sought for analysis. Table 1 shows overall conditions for each configuration.

Table 1: Monitored data in the four configurations, on a clear day, in °C

Variable	Configuration a *29 Oct*		Configuration b *2 May*		Configuration c *20 Jan*		Configuration d *11 Sept*	
	T_{out}	TC	T_{out}	TC	T_{out}	TC	T_{out}	TC
T_{max}	32,0	22,3	25,2	22,4	29,4	31,6	27,4	40,1
T_{min}	14,6	15,4	13,2	15,7	17,1	14,4	14,5	24,1
T_{swing}	17,4	6,9	12,0	6,7	12,3	17,2	12,9	16,0
T_{avg}	22,2	18,8	18,8	19,0	22,1	20,9	19,3	30,9

Ambient temperatures (T_{out}) behaved quite differently in the four monitoring rounds, with seasonal effects. Daily temperature swings varied among the four days with the highest fluctuation occurring in the shoulder season. In general, daily swings were high (>10K), which reflects local climate. Measured indoor temperatures in the test cell (TC) showed varied behaviour. The first two configurations, which tested the evaporative and function of the roof pond and the thermal mass of the water body without evaporation, but under a shading cover, had quite similar fluctuations. The two other configurations, in a shaded mode, showed higher swings. Relative differences between indoor and outdoor temperatures ($\Delta T=TC-T_{out}$) as well as the decrement factor f ($T_{swing}(TC)/ T_{swing}(out)$) and time lag (φ in hours) are presented in Table 2. The decrement factor and time lag are important characteristics to determine the heat storage capability of a given operation mode of the test cell (Asan 2006). Negative differences suggest a heating behaviour of the test cell, negative values indicate a cooling potential.

Table 2: Relative differences between internal and external temperatures ($TC-T_{out}$), time lag and decrement factors (f) for the four configurations

Variable	Configuration a	Configuration b	Configuration c	Configuration d
ΔT_{max} (°C)	1,6	3,6	2,3	16,0
ΔT_{min} (°C)	-11,8	-4,8	-4,3	6,9
ΔT_{avg} (°C)	-3,4	0,2	-1,2	11,5
f	0,4	0,6	1,4	1,2
φ (h)	3	3	0	0

The first two modes of operation (shaded) differ from the unshaded modes with respect to f and φ, raising the first and cancelling the latter. The test cell does not reduce ambient temperature fluctuations and the time-lag effect is null. As regards the effectiveness in cooling, the first configuration is significantly more effective than configuration b, meaning that the evaporative cooling function is greatly responsible for the cooling effect than the simple use of thermal mass. Indeed, in configuration b, the water-tight reservoir will add heat to the internal space. The heating capability of the test cell is noticed in configuration d, with a substantial rise in indoor temperatures relative to outdoors. The full exposure of the roof pond (configuration c) is effective for cooling purposes to a certain extent but, unless the pond is covered at night, the absorbed heat is wasted during the night. Figure 3 further demonstrates such behaviour.

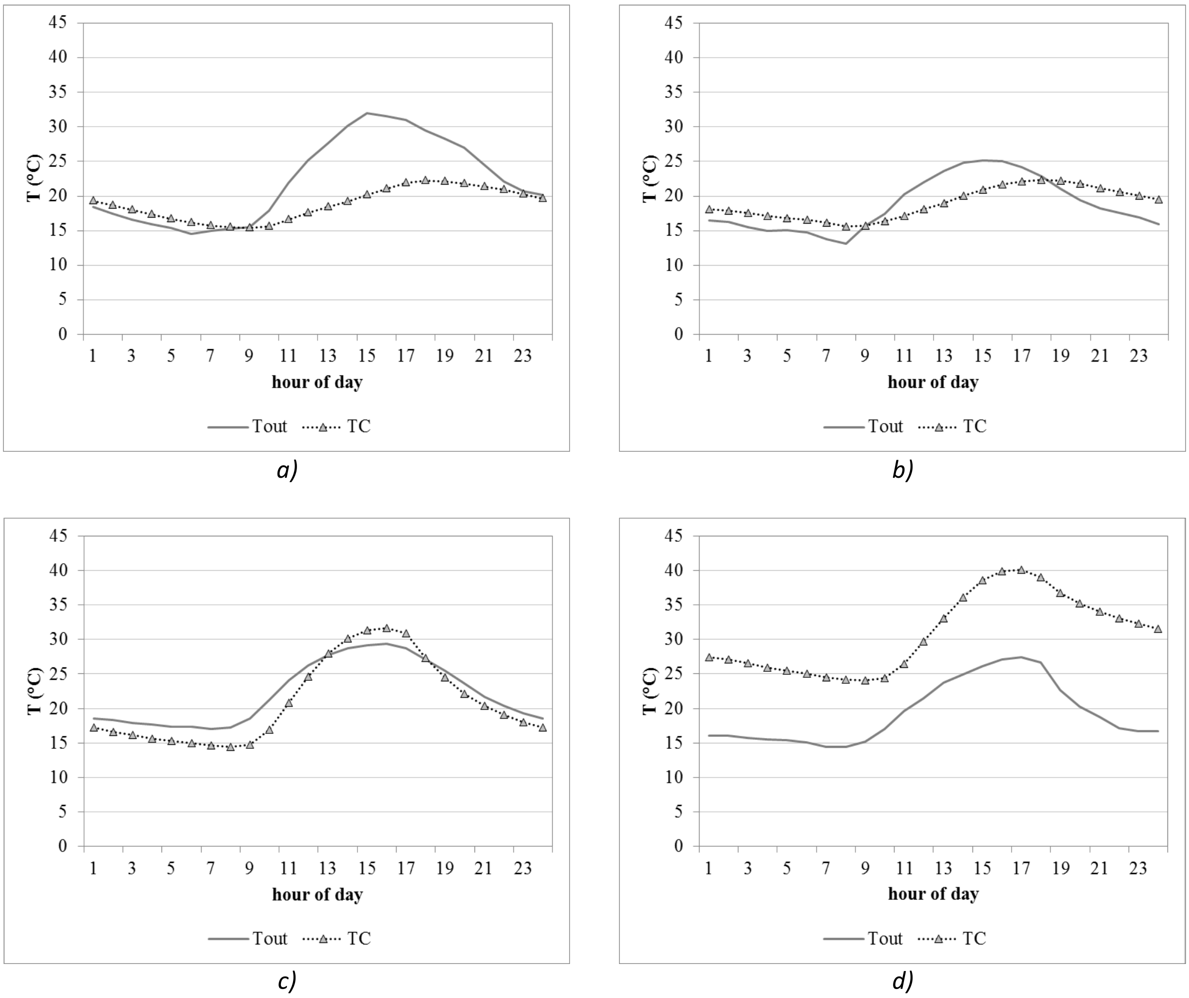


Figure 3: Indoor temperatures for the four configurations (a-d) over the background of outdoor temperatures

Indoor temperature graphs show very different relationships to outdoor temperatures. The evaporative function of the pond (a) is an important design parameter for summer operation of the system, whereas selectively covering the roof at night preserves absorbed heat during the day (d). Enclosing the water within a metallic container, permanently ventilated and under shade, with radiant cooling at night is not as efficient as allowing evaporation to take place even though a small cooling effect is noticed. The unshaded open pond, white-washed, will have not heating effect and daytime cooling due to evaporation is hindered by the direct solar warming of the water. The comparative performance of the four modes can be expressed as relative differences to ambient temperatures (Figure 4).

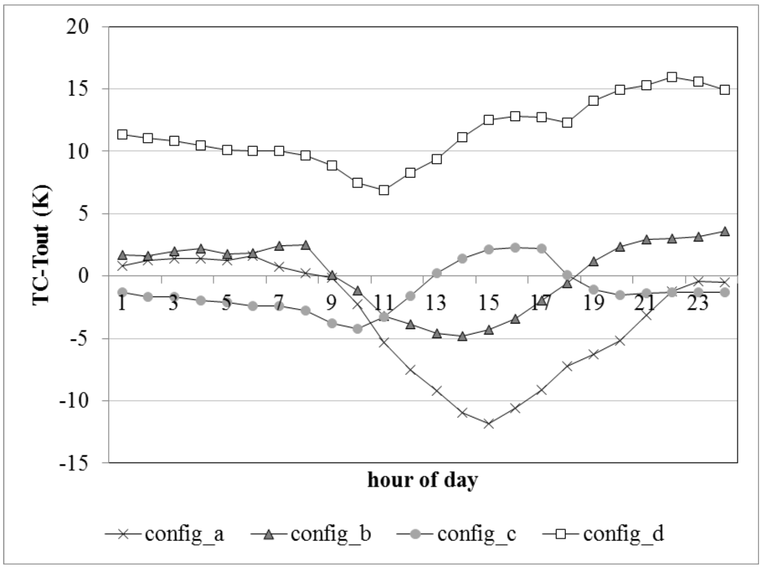


Figure 4: Relative temperature differences between indoor and outdoor air temperatures for the four configurations on clear days

Configuration d shows a perhaps unnecessary heating of the test cell which results from the solar exposure of the test cell, and due to the fact that the reservoir is painted black. Solar absorptance is increased from an estimated 0.2 (white paint) to 0.9 (black paint), which will directly influence indoor temperatures during the day due to the high conductivity of the metallic panel (assumed 60 W/(m.K)). Moreover, the increased water depth also stores absorbed heat more effectively.

Discussion and conclusions

In the case of the first configuration tested, an important parameter discussed in several studies refers to the depth of water in the roof pond. In a simulation study of a ventilated roof pond under hot-arid conditions, Raeissi & Taheri (1996) found that the increase in water depth may affect the evaporation rate per unit volume of water and therefore decrease overall daily heating requirements. Shallow water depths would thus extract more heat from the ceiling, which should be avoided in the heating season. For uncovered roof ponds, values of water depth recommended should be higher than in the case of covered roof ponds. For non-shaded roof ponds, Yannas et al. (2016) recommend that, with permanent exposure of the water pond and no spraying system, water depth should be at least 30 cm. Thus, for the uncovered roof pond to be more effective, an increase in water depth would create more stability and store more heat in the pond. According to literature, configurations a and c should optimally operate with different water depths: low water depths for covered ponds and high water depths for uncovered roof ponds.

However, a higher performance of configuration c, which showed a very high fluctuation of indoor temperature even higher than the outdoor temperature swing, according to literature, should be reached not only with increased water depth but also with an additional insulation layer (Sharifi & Yamagata 2015, Runsheng et al. 2003).

Water depth is thus an important consideration and should even affect the thermal performance of Configuration d, along with the adequate dimensioning of the opening area.

Advantages of ventilated roof ponds are many (Kharrufa & Adil 2008): low initial costs, null maintenance and running costs, low water consumption, the fact that the roof pond can be more easily embodied to the building form, among others. The drawback is the additional weight that has to be supported by the building's structure, ranging 200-400kg/m².

The experimental study provided insightful information on the operation of roof ponds, suggesting that the water tank itself with no evaporative function is not as efficient in lowering indoor temperature in summer conditions as with it. For winter conditions, night time coverage of the pond is essential for maintaining absorbed heat during daytime, yet fine tuning, i.e. local climate-related adjustments should be made as regards water depth and solar absorptance of the water reservoir. Parametric analyses are recommended to test such factors in future studies.

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Ventilation and Sound Reduction Through the Form

Ader Garcia Cardona, José Luis Arredondo R, Diego Delgadillo A, Luis Gabriel Muñoz and Jeiser Rendon G.

Abstract : Medellín (Colombia) is a tropical city located at 6, 25^{o} of the North latitude, 1495 metres above sea level, average temperatures between 17 and $28^{o}C$ and relative humidity between 40% and 80%. These conditions requires natural ventilation which in turn passes the outside noise and creates problems of intelligibility in naturally ventilated spaces. This research identified the theoretical performance of wind and sound attenuation for classroom in Medellin by evaluating scale models 1:25 of the façades of classrooms with windows, evaluated in a reverberant Chamber to scale, according to Norm UNE - EN ISO 354: 2004, ventilation measurements made in a wind tunnel CFD software simulations. Found that horizontal windows reduce 0.5 decibels the noise transmission to the frequency of 500 Hz in relation to vertical windows of the same size. For ventilation windows, horizontal and vertical, whose proportions were 1/3 and 2/3 the area of the facade, presented a ventilated area of the classroom around the 86.1% and the flow increased by 16% with on ½. Means that the windows of the classrooms of Medellín must be horizontal and in proportions of 1/3 to 2/3 the area of the facade

Keywords: vent, attenuation, noise background, windows, classrooms

Introduction

Medellin has 476 between private and public, distributed educational buildings (Anon n.d.)along the Valley of Aburrá, these buildings do not have air conditioning systems and cross-ventilation is the general technical choice. These classrooms are in areas of the city with noises of 80dBA traffic and the level of background noise in classrooms are higher than 60dBA. It is necessary to find the dimensions of the windows of the classrooms that achieve attenuation without prejudice of the ventilation. Colombian legislation NTC 4595 (Anon n.d.) requires a level of noise in the background between 40 and 45 dBA, well below the European standard that is between 30 and 33 dBA,. (Award et al. 2000) (Evans, n.d.) (Department for Education 2015) , i.e. front are a problem facing two key variables for the comfort inside the classroom that are ventilation and noise.

Procedure

For the study, evaluations were made with scale models 1:25 of the facades of the classrooms with windows located in the center and in proportions of: 1 / 3,1 / 2 and 2/3 of the size of the facade, with vertical and horizontal shapes and taking into account the requirements of the Colombian technical standard (NTC 4595) for ventilation of school classrooms, which is 1/6 of the classroom area. (INCONTEC 2006). The size of the classrooms in the floor plan was 7.20m * 4.80m, with the entrance of air into the short facade. These models are placed in an anechoic chamber on a scale where the transmission loss was measured for a 500Hz signal with a Cesva brand sound level meter.

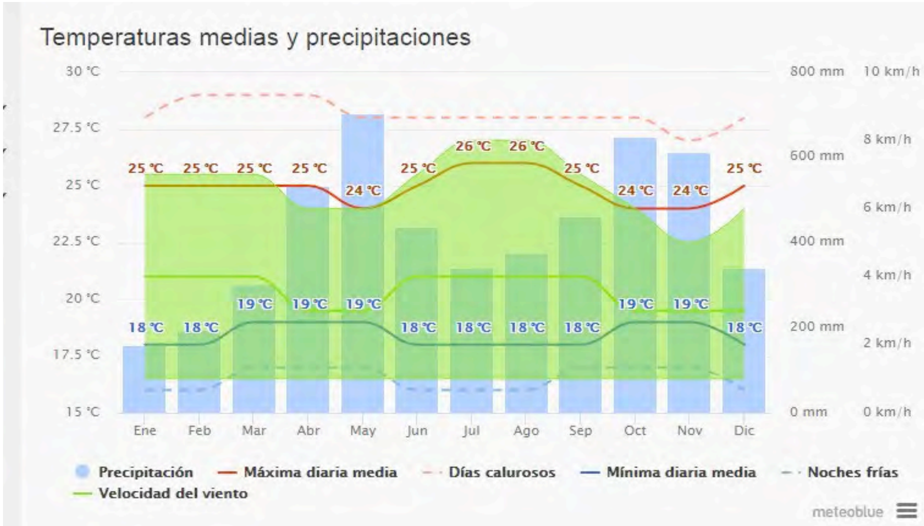

Fig 1. Average temperatures and the wind speed in the city of medellin. Retrieved from https://www.meteoblue.com/en/weather/archive/histogram/medell%C3%ADn_colombia

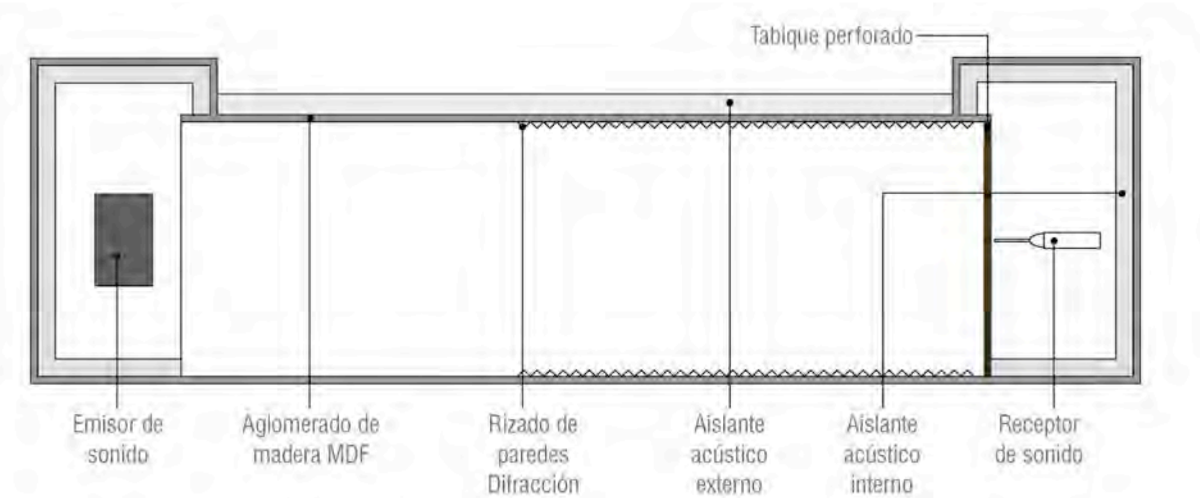

Fig 1 anechoic chamber section

The device or anechoic chamber is composed of two devices at the ends in which in one of them is located the sound source and in the other is the receiver or sound level meter. The chamber is constructed with 19mm agglomerated wood lined inside with expanded polystyrene of medium density of 50mm thickness, and outside lined with a 2 "layer of rock mineral wool. Figure 1 shows section of the chamber and the location of the perforated panel with the window gap in the proportions mentioned.

According to UNE-EN ISO 354: 2004 standards, the minimum frequency at which measurements can be made is one whose wavelength is equal to the length of the shortest edge of the chamber, in the case of the chamber used, that frequency corresponds at 500Hz.

Measurements and observations of indoor ventilation behavior were done in wind tunnel and in CFD software. In order to carry out the evaluation of airflow in the wind tunnel, a scale model in acrylic was used and it was recorded by means of photographic shots. These same conditions were simulated with a CFD software to know the internal wind speeds and the propagation of the flow through the space.

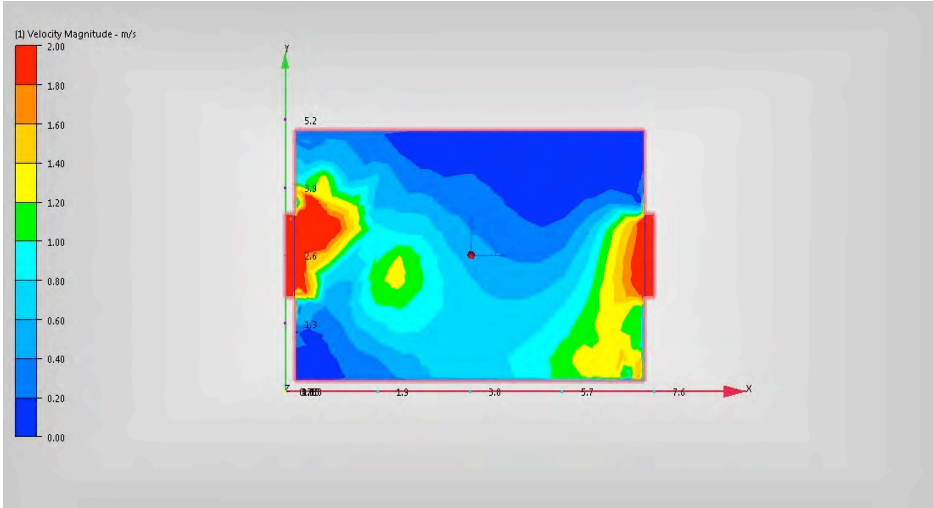

Fig. 2 effective ventilated area for 20.6 m2 to no avail 1/2 horizontal

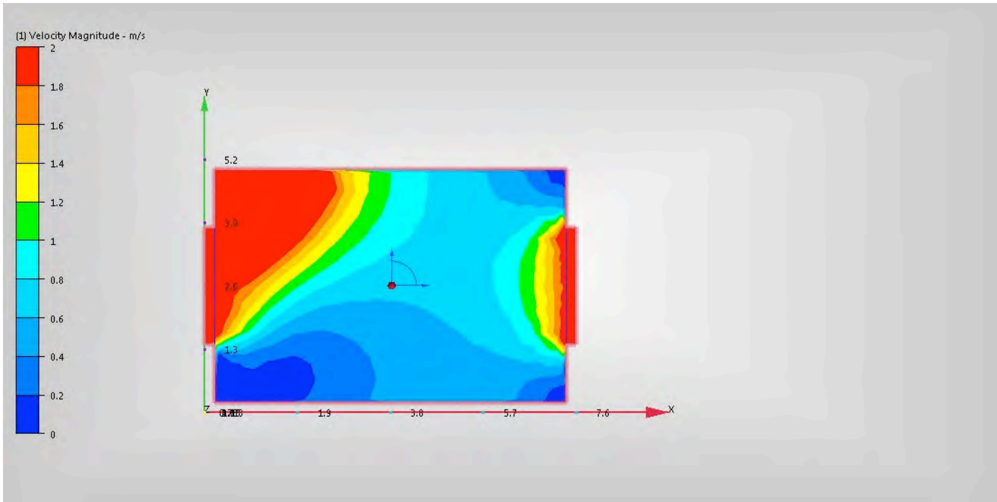

Fig 3 effective ventilated area for 26 m2 to no avail 1/3 horizontal

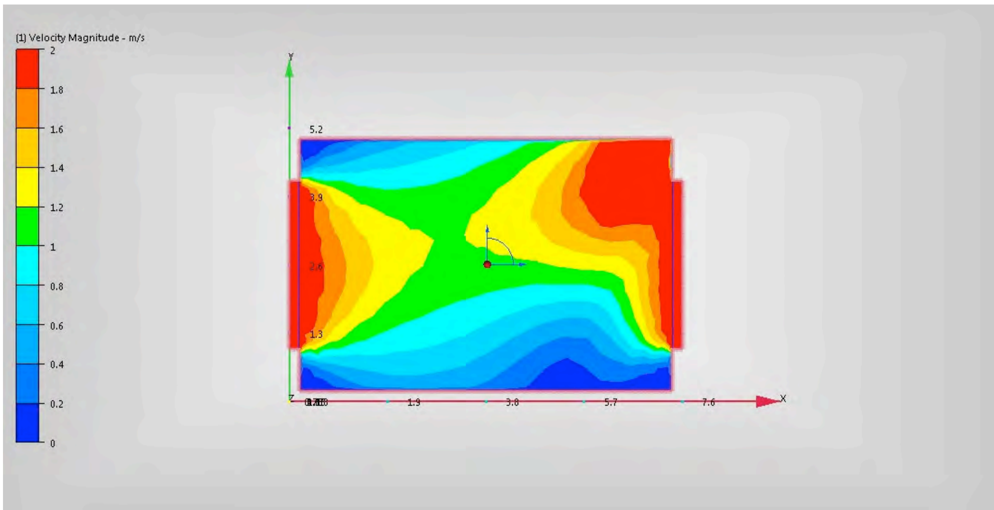

Fig 4 effective ventilated area for 29.7 m2 for vain 2/3 horizontal

As an experimental control is calculated flow of ventilation with the following empirical formulas:

Ventilación debida al efecto del viento

$$Q_w = C_d A_w V \sqrt{\Delta Cp}$$

$$\frac{1}{A_w{}^2} = \frac{1}{(A_1 + A_2)^2} + \frac{1}{(A_3 + A_4)^2}$$

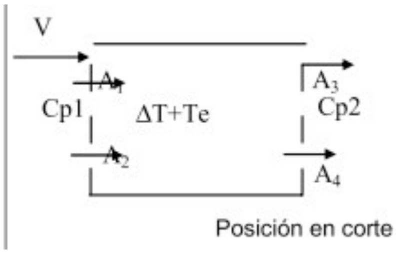

Fig 5 formulas taken up cross-ventilation (Anon n.d.)

Q	flow
cd	discharge coefficient
A	area openings
v	wind speed
ΔCP	pesion coefficient Delta

(Anon n.d.)

Results

Comparing the results of formulas with the CFD models are ventilated percentages of the classroom:

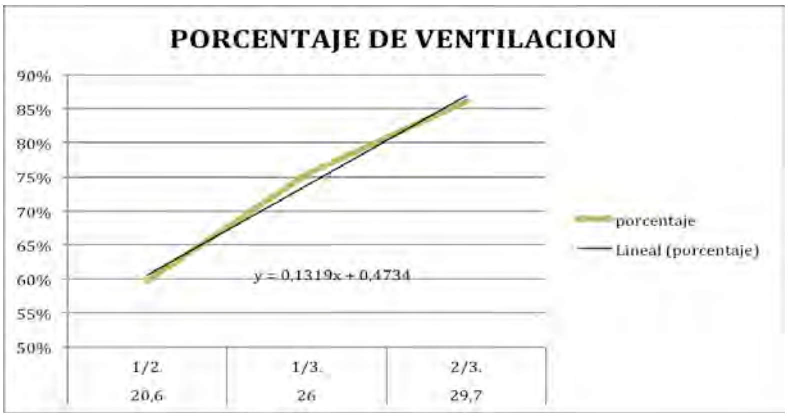

Fig 6 percentage of area ventilated vrs vain proportion. Execution

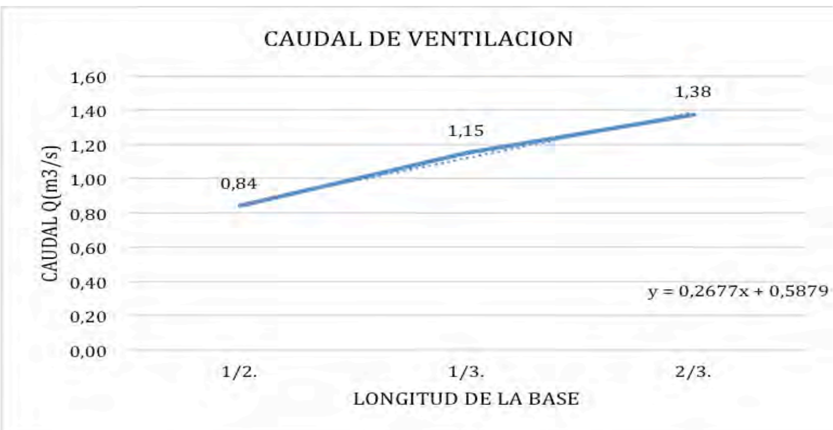

Fig. 7 flow of ventilation. Execution

Noise attenuation in regards to the ratios 1/2, 1/3, 2/3 is presented in Table 1 and in Figures 7-9.

Table 1 results of measurement in anacoica execution Chamber

Position of the vain	LeqA	500Hz	1000Hz	2000Hz	4000Hz
BACKGROUND NOISE	77.89	34.60	32.93	37.67	40.80
1/3 - Horizontal	100.68	70.43	73.37	80.13	80.53
1/3 - Vertical	100.53	70.93	72.50	79.20	82.63
1/2 - Horizontal	101.57	74.33	74.83	79.20	81.50
1/2- Vertical	101.83	74.73	75.17	80.93	81.10
2/3 - Horizontal	101.23	71.97	73.40	78.97	80.20
2/3 - Vertical	101.23	72.83	73.60	79.77	81.53

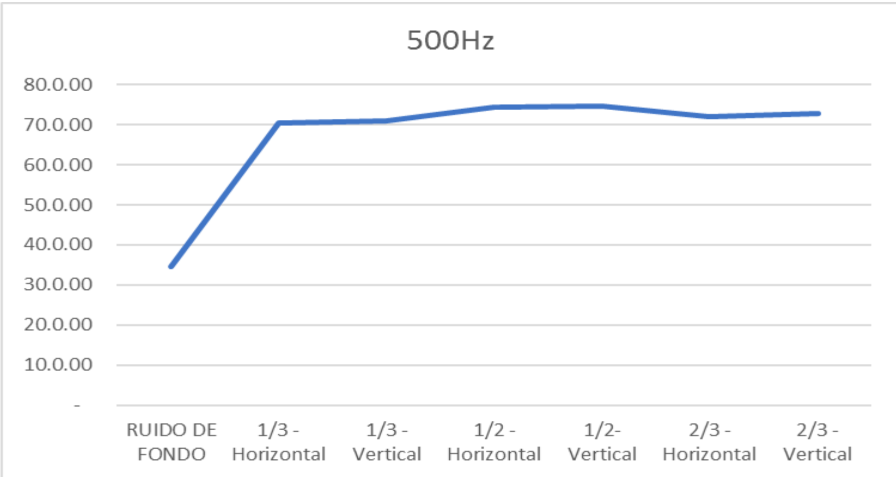

Fig 7 behavior of attenuation in the range from 500 hz execution

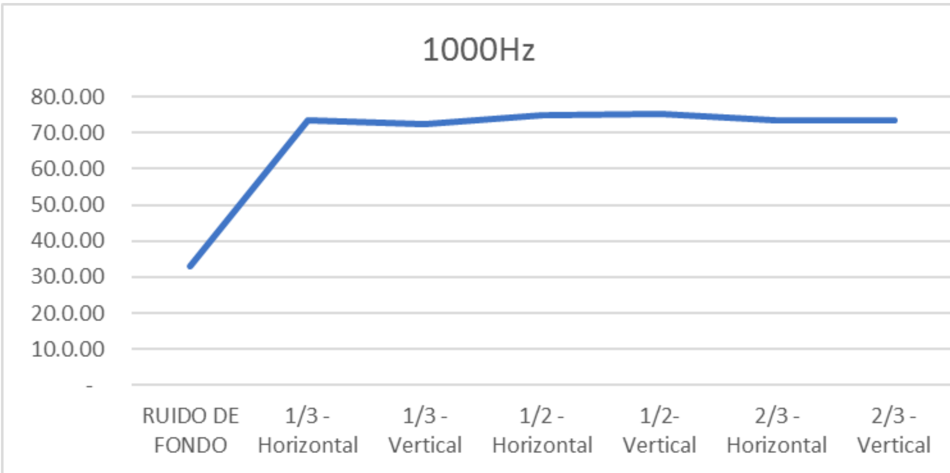

Fig 8 behavior of the attenuation at 100 hz execution band

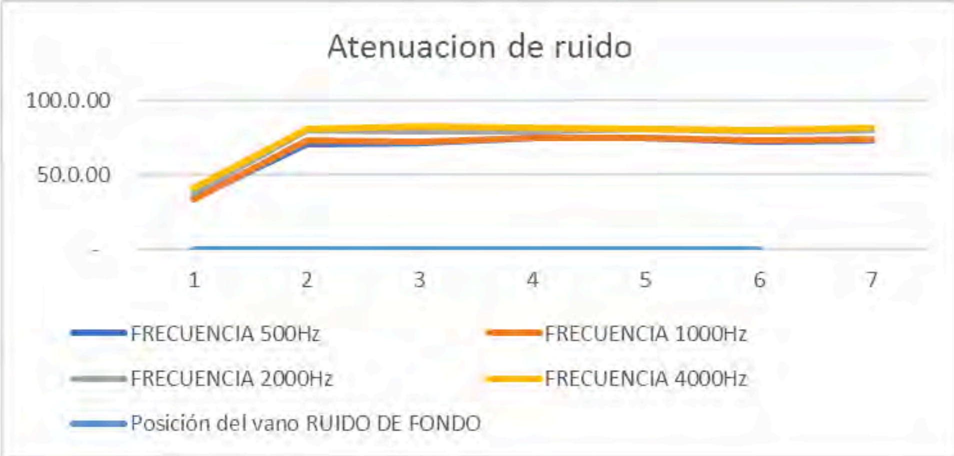

Fig 9 behavior of attenuation in 500,1000,2000,4000 HZ band execution

Discussion and Findings

Analyzing the results of the attenuation of the noise according to the shape of the window, it was identified that the horizontal proportions in the 500 hz band are that presented greater attenuation, between 0.5 and 0, 86dBA, with ratios of 1/3 and 2/3 that presents higher attenuations. For high frequencies in the band from 4000 Hz higher attenuations are for windows with ratios of 1/2 y2/3, falling between 2 and 4dBA.

Models CFD noted that the areas and the speeds of the air inside of the classrooms did not exceed 1, 2 m/s and that the flow increased by 39% when the window passes proportions 1/2 to 2/3, covering an effective area of the enclosure of 86.1%. For windows with ratios of 1/3 the percentage of effective ventilated area within the classroom is a 75.36% and for a window with a proportion of ½ percentage of ventilated area is of 59.71%, the upsell benefit ventilated ara of ½ to 1/3 ratio is around from a 15.65% and the increase from 1/3 to 2/3 is from the 10.73%.

In summary the horizontal proportions of windows reduce between 0.5 and 0, 86dBA noise for the frequency of 500 Hz transmission. In ventilation change in proportions of 1/3 to 2/3 both for horizontal windows as vertical increases the ventilated area of the classroom around 16% and the flow rate by 16%. To say that the windows of the classrooms of Medellín must be horizontal and in proportions of 1/3 to 2/3 the area of the facade.

Conclusions

It is that for classrooms of Medellin's elongated proportions with air intake for its façade and shorter the best proportions of windows are 1/3 and 2/3 the area of the facade. Likewise these proportions are presenting greater attenuation noise for 500 Hz band. 4000 Hz frequency windows with proportions of 2/3 and 1/3 attenuated between 1 and 2dBA. In summary the best proportions for ventilation and attenuation of noise at 500 hz band are 2/3 and 1/3

Register photographic process

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Design to Thrive

Low cost, energy and impact ceramic cladding cooling system by means of evapotranspiration or ‘botijo-effect’

Javier García-López

Instituto Universitario de Arquitectura y Ciencias de la Construcción, Escuela Técnica Superior de Arquitectura, Universidad de Sevilla. Email javigalo@us.es

Abstract: A new ceramic cladding system was first applied in the house prototype named "SOLARKIT”, representing the University of Seville in the international competition Solar Decathlon Europe 2010, where its effectiveness was registered by thermographs y and the monitoring of the building. Therefore, as a result of this R+D+I experience derived from the search of a low energy and innovative cooling bioclimatic strategy, a new cladding system has been invented and patented. Consequently, the patented invention relates to an external cladding system using tiles made from a porous-ceramic material or similar, named as a façade with “botijo-effect”. Thus, the system can be applied directly as a final cladding or used in external sheets of ventilated façades. Compared to traditional claddings, this system provides de possibility of cooling its surface by means of evapotranspiration generated by supplying water through a network of canaliculi inside the tiles. An estimated superficial cooling power of over 80 W/m² can be considered, plus an 8 to 10ºC cooling effect on the air temperature Its application is particularly interesting at locations with hot-dry climates where there is a high cooling energy demand or where is intended to mitigate the "heat island" effect in urban environments.

Keywords: evapotranspiration, botijo effect, ceramics, patent, biomimetic technology

Introduction

The use of techniques of using water cooling or "evaporative cooling" in buildings has been present in architectural culture Andalusian, North Africa and the Middle East for centuries (J.Neila). Examples have survived until the present day in the form of archetypes such as the Andalusian patio, or monuments of the Nasrid Alhambra and Generalife of Granada architecture. Ventilation chimneys, originating in the Middle East, also use the cooling by humidification and dehumidification to downdraught cooling the interior of the buildings (B.Ford, S.Álvarez et.al).

Contemporary examples of the use of surface evaporation in ceramic materials as passive conditioning technique can be found in the forest of ceramic pillars of the Pavilion of Spain at Expo-Zaragoza 98 designed by Francisco Mangado, or in the ‘bioskin’ ceramic tube brise-soleil façade of the Sony Osaky Building in Tokyo (V.Lerum), designed by Nikken Sekkei.

Figure 1 SolarKIT prototype at Solar Decathlon 2010 with ceramic ventilation towers ©R. Santoja

Fundamentals

The ambient water surface evaporation is an endothermic process, which absorbs energy. This energy or heat of evaporation is provided by direct conduction through the materials from the environment such as water or a solid saturated of humidity as the ceramic element or other porous materials. This phenomenon is based on traditional techniques of cooling as the botijo (Fig 2), a type of Spanish handmade ceramic jug, which keeps it cool the water content for your drink thanks to its surface evaporation.

The operation of the botijo has come to be described through a very complex formulation, according to published authors J.I. Zubizarreta & G. Pinto (J.I Zubizarreta et al, 1995).

Figure 2 Botijos from La Rambla ©M. Ruiz Díaz

There is something which, however, is not so difficult to quantify, as it is cooling due to the water evaporation capacity. The energy used in the evaporation of water at room temperature is called heat or enthalpy of evaporation, and can be obtained from the electricity tables. At room temperature, we can consider it as 580 kcal/kgH20 (2426 kJ/kgH2O), i.e. 580 kilocalories are absorbed for a kg of water evaporates.

The so-called "mass transfer coefficient" or k' (kgH2O/hm²), estimated at 80 kg water/hm² according to (J.I Zubizarreta et al, 1995), describes the amount of water that "sweat" or passes the jug to its surface per unit area and time. This factor is the key to the ability of a surface cooling with cooling by evapotranspiration, as in the case of crops, where they join the phenomena of evaporation of water from the ground and plants.

The amount of energy extracted per unit area "botijo" and time will be

$Q=k'*H$,Being H = enthalpy or heat of vaporization (580 kcal/kgH20 = 2426 kJ/kgH2O) k'=80 (kgH2O/hm²) [1]

Then for each surface unit is would extract 53.9 joules per second, equivalent to a cooling of 53.9 Watts power per unit area (m²).

B. Morillo recent experiment has measured up to 0.224 kg/hm² of surface evaporation, equivalent to a 140 W cooling power per m².

This cooling capacity described as energy removed per unit time is getting cool the water of the pitchers, and in practice can be used in other applications as thermal building conditioning, as we will see below.

Considering these fundamentals, the geographic areas with greatest potential for exploitation of surface evaporation for the new or the refurbishment of the buildings will be those with a climate of warm, dry summers as regions with Mediterranean climate.

Problem to be solved

This section discusses the technical problem which is given solution by the new invented system. This problem could be formulated using the following questions:
Is it possible to incorporate the surface cooling to the wall of a building by means of a simple and passive technology?

Would it be possible to take advantage of this effect of surface cooling to provide air cooled flows without the contribution of additional moisture?

Origin

The origin of the invention arises during the design of a low-energy system for ventilating a housing prototype, SOLARKIT for the Solar Decathlon 2010. To this end an initial design of a ventilation chimney was developed resulting in an innovative ventilation tower (Fig 3) from the combination of solar chimney and breezes capture tower, through which the air intake and expulsion is resolved.

That new bioclimatic component combined the downstream or downdrought cooling effect to cause outside air intake, pre-cooling it by means of the evaporative cooling effect of the ceramic cladding of the north face duct before being fan-forced distributed into the building through an edge-sealed raised-floor plenum. Subsequently, the effect of solar chimney of the south face of the tower provides the extraction of indoor air without mechanical support by stack effect, since the thermal inertia of a water reservoir placed in the core of the tower keeps the thermal draft effect even when no solar radiation is available.

[1] According to experiment described in article of *J.I Zubizarreta y G.Pinto*

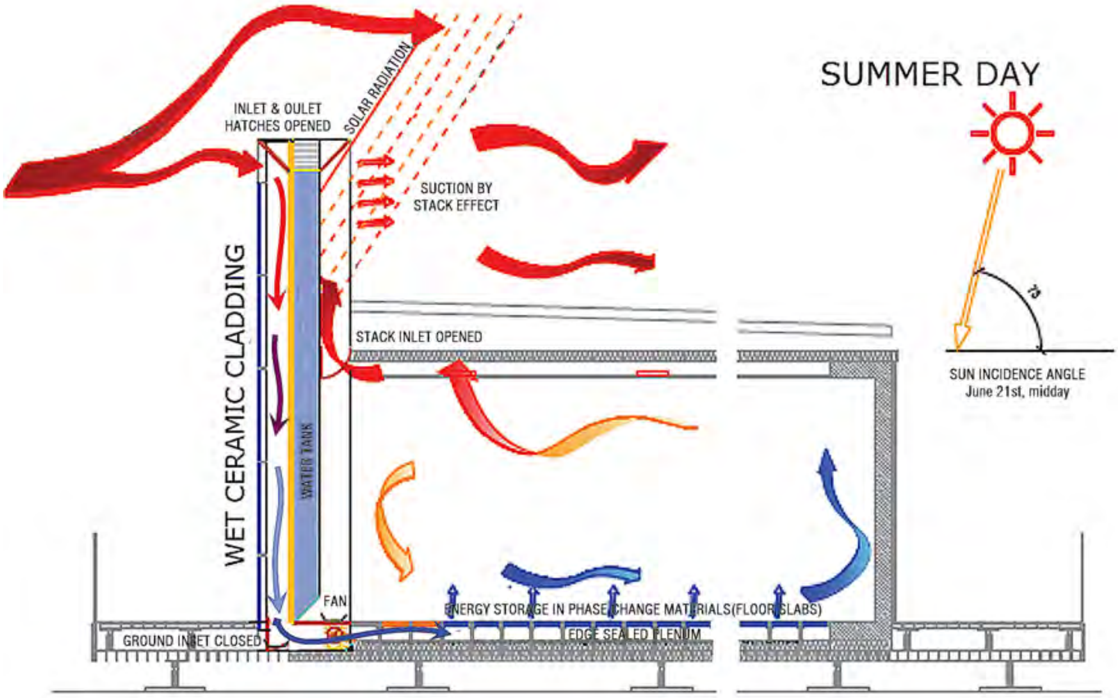

Figure 3 SOLARKIT's Ventilation tower scheme. Summer-day period.

Tests and prototypes

We found the first example of realization of this ceramic cladding tile in SOLARKIT, (Figs. 1 and 4) as it has been described in the previous point.

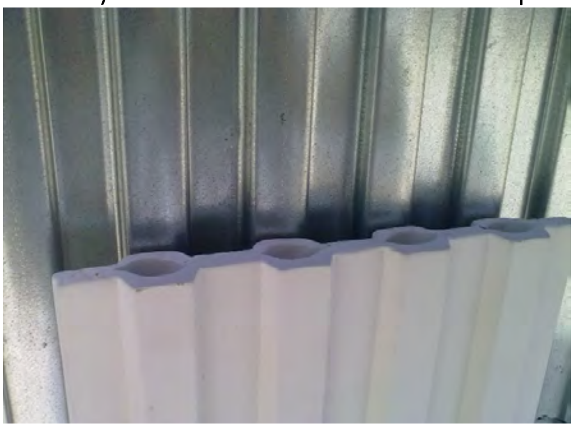

Figure 5 Porous ceramic cladding tile designed for SOLARKIT's ventilation towers

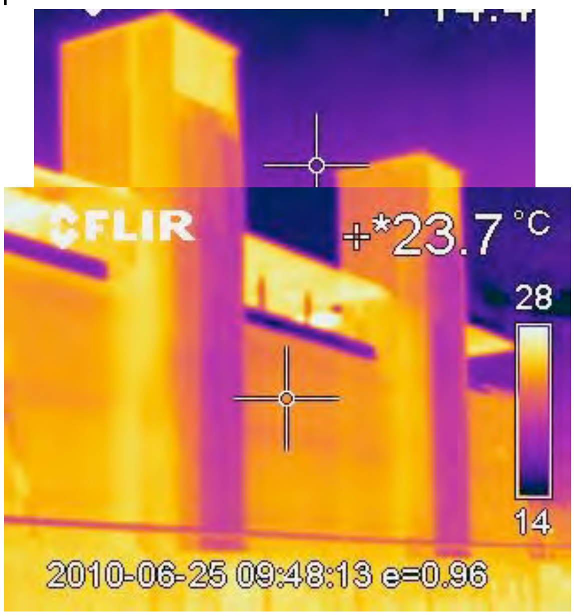

Figure 4 Thermograph image of ventilation towers with activated ceramic cladding cooling system of SOLARKIT

As a proof of system operation by thermographic images (Fig 5) it can be observed the difference in surface temperature of the wetted ceramic facings (front side) against those who are not (left and right sides)

Regarding air temperature, there has also been recorded and monitored up to 7 degrees differences between the outside (29°C) and the output of the tower at its base into the housing (22° C) without the addition of extra moisture.

The second experience where the system has been applied was in the prototype “Patio 2.12” participant in Solar Decathlon 2012 (Terrados-Cepeda F.J, 2014). However, in this case its application did not follow all the patent requirements, such as the use of a ceramic material with a high degree of porosity. The baking treatment and the surface glazing of the commercial terracotta tiles used prevented an effective evaporative desired for the passive conditioning effect (Fig 6) of the prototype as originally planned.

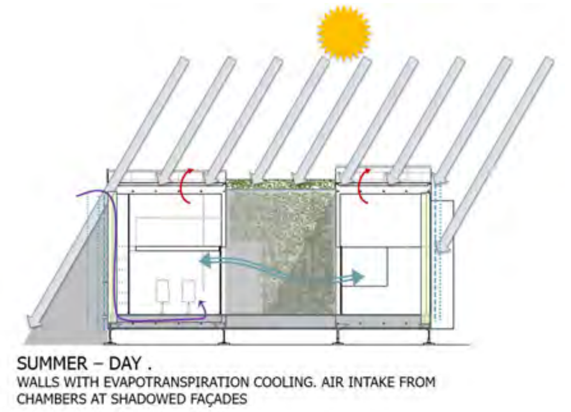

Figure 6 “Patio 2.12” bioclimatic strategy combining green-house and botijo-effect

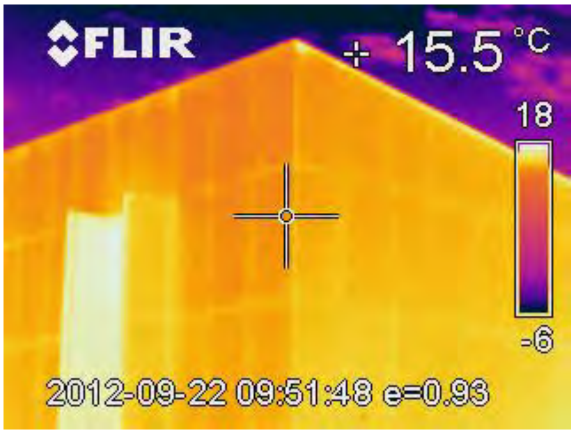

Figure 7 Patio 2.12 corner with (left) and without watering (right) at the same surface temperature

Thermographic images (Fig7) show little difference between the ceramic facades with activated watering effect and the conventional ones without water supply.

Nevertheless, this experience helped to document the influence or effect of water evaporation and the degree of porosity to allow its outcrop in the appearance of the surface cooling phenomenon. Its actual low performance in the prototype did not avoid, however, that the concept were widely celebrated by the jury and the public of the competition, which resulted in an excellent 2nd place in the competition.

Patent

Finally, in 2012, after the first satisfactory experience with SOLARKIT it was decided to promote the patent process since a high degree of innovation and novelty was detected.
Patent with prior review process has finally been completed (Patent nº ES2455415_A1) with granting a protection for 20 years.

IBI international search and reports on the State of the art in the PCT process remarks the high degree of novelty of the invention by granting a "class A-not relevant" international reference patents[2], to the main claims

In particular, it highlights the fact that provided moisture happens in the entire piece and that the contribution of water occurs by gravity, from the interior alveoli to its surface in a natural way.

Description of the system

The invention consists of a novel solution of cladding for buildings or constructions using a covering ceramic tiles or other porous material similar with a controlled water supply through a system of internal canaliculi where water flows by gravity. The evaporatation of the water

[2] (see final patent references)

absorbed by the pieces on its outer surface produces a surface cooling wich helps to reduce the surface temperature of the enclosure, and therefore, the Interior of the building.

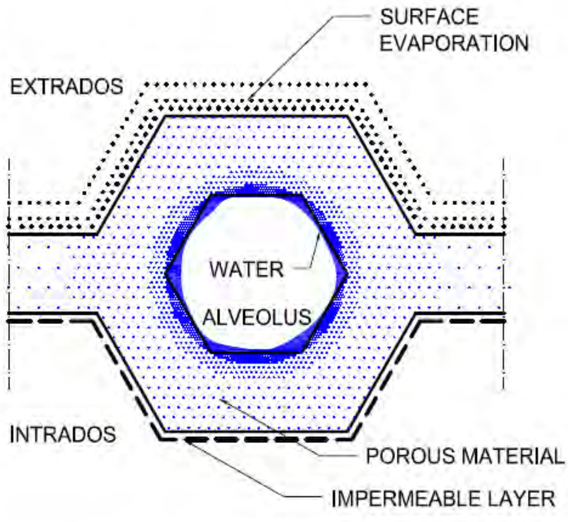

Figure 8 Horizontal section by alveolus type.
Evapotranspiration functioning.

The solution consists of elements and traditional building materials. For the operation or activation of the cooling it only needs a small supply of water to evaporation (about 0,22 dm^3/h or 1,45 dm^3/day per m^2 of façade), which can come from retrieval systems of water rain or recycling within the same building, thus reducing the demand for drinking water for their operation.

The system can be applied to walls of buildings and constructions as direct liner, using fixing techniques applicable to other stone or ceramic claddings. Equally, the system can be arranged in an indirect mounting as outer foil in ventilated facade constructive solutions.

The cooling of the surface can be used to reduce the external temperature of the enclosure, and therefore, the gain of heat transmission.

In addition, applied as the outer sheet in "ventilated facade" solutions, it can be applied for cooling the air at the chamber, which, in turn, can be used as cooled passive, natural and free of charge flow for the ventilation of the interior spaces of the building,

Functioning

Surface of this facade system cooling capacity is especially suitable for buildings or constructions at hot and dry summers climates, and wich facades prevail massif front windows. The watering system should be activated during periods of maximum insolation and higher outer temperature to optimize or cold seasons it should remain disabled.

The effect of surface evaporation benefits on the one hand inside the building by lowering their surface temperature, but also affects the near environment of buildings, since the contribution of additional moisture contributes to lowering the temperature around the building, and thus reduce the "heat island" effect.

Application

This described finishing system can be applied to the closure of the buildings in two ways:

The first or "direct fixing" consists of a solution of fixing the elements directly to the facade, whether by anchors mechanical or even with epoxy-type adhesive, to the outer layer of wall, as in a conventional solution of cladding with pieces of stone, ceramic tiles, etc. In this case the surface cooling by evaporation, when environmental conditions demanded it, would lower the temperature of the outer face. Cooling is directly transmitted this way by "transmission" to the Interior of the wall layers, which would reduce heat gain through the facade in summer conditions.

The second mounting option would be "indirect fixing", consisting of the use of a substructure or auxiliary support to hang it from. It should provide a continuous air chamber of approximately between 3 and 10 cm thickness between the outer ceramic tiles and the interior of the wall sheet.

At the bottom and the top of the façade there should be some adjustable openings in order to regulate the entry of an airflow to the air chamber. Finally, air intakes will be installed at the air chamber connecting to the inner spaces or to the mechanical ventilation of the building.

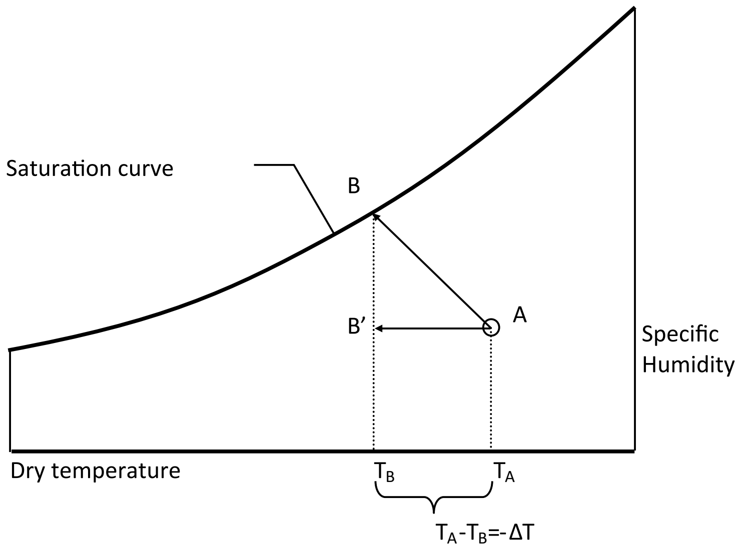

Figure 9 Sensible cooling process AB' Vs evaporative cooling AB

When reaching the thermal equilibrium, thanks to the evaporative cooling process in the outer layer surface, the air contained in the chamber will cool from the dry temperature point “A” of the outside environment until the wet bulb temperature at which the outer layer will be, but without having increased its moisture content, thus running a "sensible cooling" psychrometric process (AB' in Fig. 9).

Air cooled this way can then be introduced into the building through the admission intakes placed at the air chamber and used as a naturally and free of charge pre-cooled (-ΔT in the figure) ventilation air-flow.

This technique can reduce or even eliminate the ventilation loads in summer as the air brought in from outside, and previously cooled through the chamber reaches the interior with a temperature close to summer comfort conditions. This is particularly interesting in commercial buildings with large ventilation requirements.

It has been registered (F.J.Neila) that natural convection phenomena generally manifest at air chambers over 10 cm thick. During the surface cooling operation of the facade, air cooled in the thicker than 10 cm chamber will flow to the bottom by a natural downdraught effect. This is of particular interest in implementing this as a cladding system of bioclimatic elements such as ventilation towers used for low energy and passive air conditioning of buildings. The described ceramic coating would help to enhance the downdraught cooling effect at breezes-capture and ventilation towers as tested in Solarkit.

Conclusions

There has been presented a new and original system for passive cooling buildings, which originality has been certified by the patent authorities.

Not only is able for cooling buildings and constructions façades, but also to produce fresh air for buildings spaces' conditioning and ventilation.

Its functioning requires no energy supply but a continuous small amount of water in order to generate the cooling effect named "botijo-effect".

A set of simple devices for temperature and humidity monitoring with a control system acting over the watering system is required to optimize and manage its performance.

The surface cooling effect highest potential is located at regions with hot a dry summer periods, with a high range for evaporative cooling capacity.

The system performance will be increase when applied in façades without direct sunlight.

Arising from the state of the art and the built experiences described an estimated superficial cooling power over 80 W/m² can be considered, plus an 8 to 10°C cooling effect on the air temperature, with a total 1,45 l/m² of water per day. Both characteristics has been confirmed by means of direct measuring and thermography images.

A high potential for future developments can be foreseen considering its low cost, energy and impact for easily cooling buildings surfaces with tradition rooted techniques.

Acknowledgments

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Redeveloping Informal Settlements in Kolkata: A vernacular approach to 21st century design

Oindrila Ghosh[1] and Paula Cadima[2]

[1] Design for Climate and Comfort Lab, Singapore University of Technology and Design, Singapore. Correspondence email: oindrila_ghosh@sutd.edu.sg
[2] The Architectural Association School of Architecture, London, UK

Abstract: Slums are ubiquitous in cities in all tropical regions and India is no exception. Half of the urban population of India lives in slums and in response to this ever-growing problem, large-scale resettlement colonies get built by the government on the city edge as “solutions”. However, these slum interventions end up failing as they do not address the issue of providing a “good environment” to the urban poor that make these megacities run. This research paper tries to address this loophole and its objective is to provide a modular, replicable, adaptive and sustainable residential unit made with locally available materials and suggest passive design guidelines for a holistic and successful slum redevelopment in Kolkata. Fieldwork is carried out to supplement this objective by understanding the aspirations and present living condition of slum residents. Also, performance of the local vernacular materials and passive design strategies were tested to translate them into the 21st century design of the modules.

Keywords: slum settlements, vernacular architecture, tropical design, traditional materials

Introduction

Slums are gateway to the cities for the rural people of India. They migrate with the hopes of a better lifestyle and find shelter in these informal settlements. The mega cities of India don’t have enough infrastructures to house such influx of people. This paper discusses a research focusing in Kolkata which houses the second largest slum population in India after Mumbai, (Ghosh 2016).

Slums typically begin at the outskirts of a city, located on least desirable public lands or lands with no clear land title. Over time, the city may expand past the original slums, enclosing the slums inside the urban perimeter, Figure 1. This makes the original slums valuable property, densely populated with many conveniences attractive to the urban poor. It is also a place where a lot of wealth as well as crime are generated. Slum dwellers afford a lot of modern day equipment for their daily life but only at the expense of their low-cost living conditions in the slums (Bakshi, 2013). Thus, holistic passive redevelopment can drastically improve the social and environmental quality of the resident’s lives.

The climate of Kolkata is hot and humid with high solar radiation both direct and diffuse. Mid-March to mid-June are the most problematic months, as air temperature ranges between 25 to 30°C with relative humidity levels reaching well up to 100%. As seen in Fig. 5(b) Kolkata receives a lot of horizontal as well as diffuse radiation. The comfort band ranges from an average of 25.6 to 31.6 °C, the project uses Nicol’s equation ($T_c = 0.534\ T_o + 12.9$) for adaptive comfort (Nicol, 2004). Environmental strategies call for the building envelope to work as high thermal mass during the day and low thermal mass at night for optimal comfort in this climate.

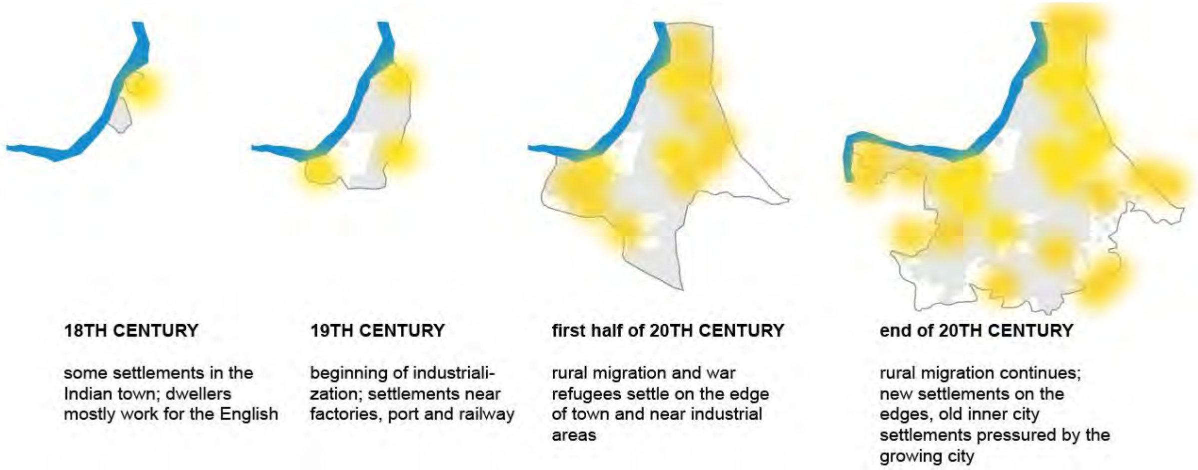

Fig. 1. Timeline of the growth of the city and the simultaneous burgeoning of slums. Source: After Herz, 2008.

Methodology

Spot measurements and slum surveys were carried out in two slum settlements in Kolkata to identify the occupant behavior, existing living conditions and aspiration of the slum residents. The data recorded also enabled the calibration of a base case scenario for thermal simulation studies.

Further fieldwork was carried out in Silchar, Assam which has a climate like Kolkata. The objective was to study four similar huts which were primarily made of 4 locally available materials like bamboo, wattle and daub, mud and traditionally available brick and mortar. Data loggers were installed in the bedrooms of these 4 huts over a period of 1 week. Resident's survey supplemented the study with useful information about the environmental and economic performance of these materials and supported the analytic work.

The information collected from fieldwork helped establish a base case model for simulation using EDSL Tas software. Subsequently, design modifications and alternative scenarios were proposed through step by step interventions to achieve a free-running residential unit.

Fieldwork

Two slum sites were visited: South city (illegal squatter) and Shahid Sriti (legal settlement), Fig. 2. The slums are 35 and 100-150 years old, respectively. Its residents work as maids, drivers in the service industry for gated communities, hospitals etc. around that area. Both the slums are located near a water body, in a low lying marshy area. This indicated that such illegal development generally occurs in unwanted spaces with a water connection.

Fig. 2. Existing slum conditions; Shahid sriti (left) and South city slum (right).

Existing slum conditions:

All basic resources are present but scarce and therefore everything is shared. Environmentally, they are in great discomfort during summer season because of the following reasons:

1. Poor dilapidated hut envelope leading to high heat gains from the leaky roof.
2. High internal heat gains from kitchen trapped inside as they have no or only one window.
3. Dense urban scenario also trapping the anthropogenic heat due to high population density.
4. High humidity levels combined with high air temperatures.
5. Flooding issues during the end of summer and monsoon period.

Winters in Kolkata are usually mild; therefore, this study focused on mitigating the summer problems.

Material survey:

The fieldwork undertaken to identify the material performance of the vernacular materials revealed that the use of the generic brick construction helped for a better thermal performance. Figures 3a and 3b present the summarized comparison of all the materials that were measured over a period of two weeks. The average temperature difference between the external and the indoor temperature was lowest (-0.1K) in brick constructions, followed by units made from mud (-0.6K). Mud performed similarly to brick due to its high thermal inertia even in units with a leaky construction, without false ceilings and mechanical fans. Therefore, mud and brick can be used in places with higher solar exposure. The unit built in wattle and daub with the thatch roof performs third best (-0.9K), followed by that built in bamboo (-1K). Materials with low thermal mass should be used in places with lesser solar exposure and require judicious study at preliminary design stages.

The study here deals with mitigating all the issues that were encountered during the fieldwork and supported the development of a free running comfortable prototype unit that can be potentially replicated throughout other locations.

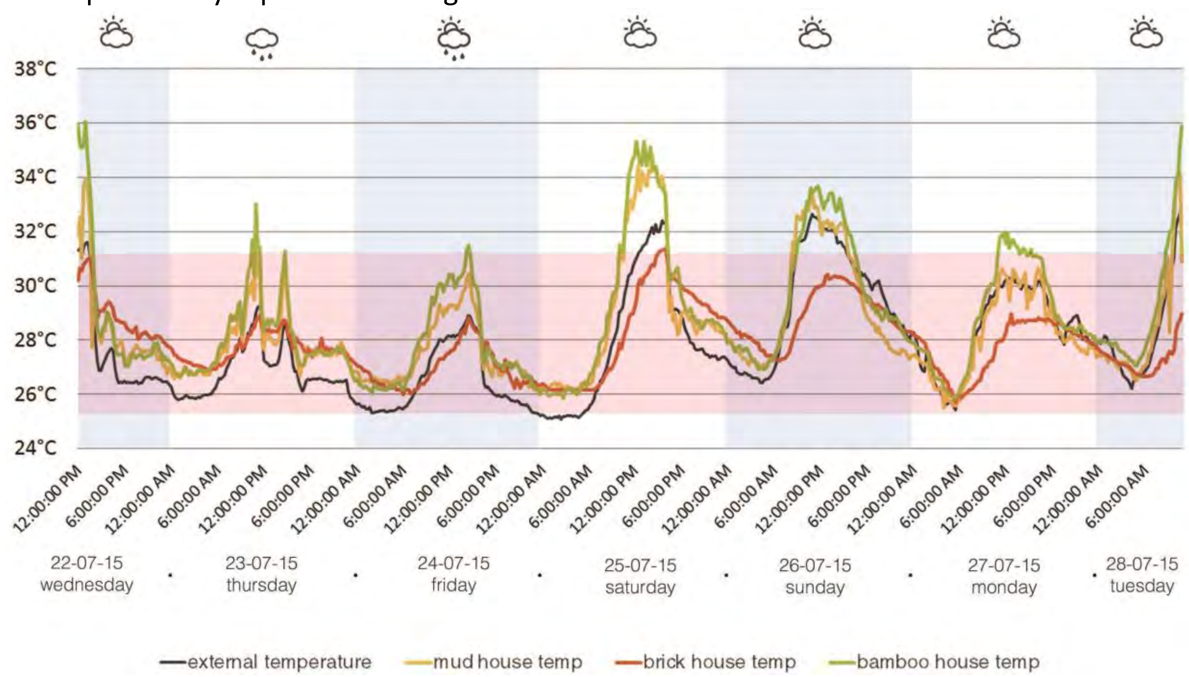

Fig. 3a. Indoor temperature measured during one week in units built in mud, brick and bamboo.

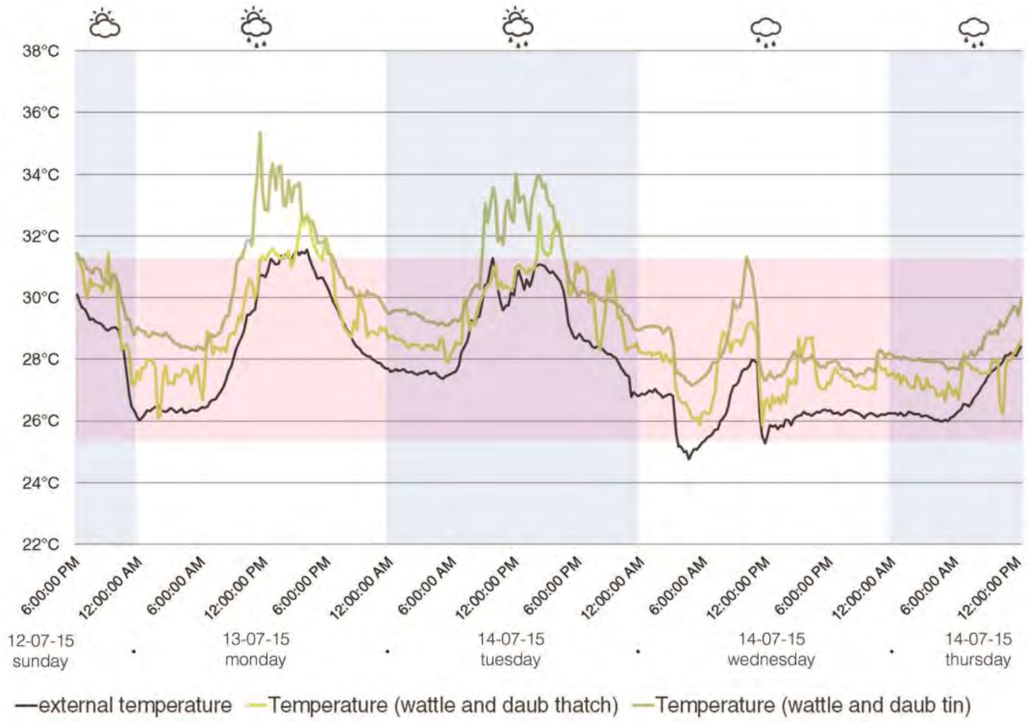

Fig. 3b: Indoor temperatures during one week in units built in wattle and daub thatch and wattle and daub tin.

Design of the dwelling unit:

A dwelling unit was used as a prototype for the study with construction specifications described below and design characteristics shown in Fig. 4. An area of 25m^2 was allotted for each unit based on minimal anthropological requirements and regulations from the National Building Code of India (NBC, 2005). The dwelling unit is designed to have 2 bedrooms and a kitchen. The design is kept simple for ease of construction by participating families. Toilet will be a shared facility amongst the residents.

Thermal analysis of base case:

The prototype incorporates all the existing problems identified in the slum settlement during fieldwork. The following input data was used for thermal simulations.

Floor Area: *25m²* Occupancy: *4 occupants*
Wall U-value: *2.6 W/m^2 K;* Floor U-value: *1. 7 W/m^2 K*
Roof U-value: *4.7 W/m^2 K;* Bamboo mat board U-value: *4.1 W/m^2 K* (ceiling)
Infiltration rate: *1 ac/h;* Ventilation rate: *1.7 ac/h*
Lighting Gains: *3.69 W/m^2 (bedroom) + 2.7 W/m^2 (kitchen)*
Occupancy Sensible Gain: *17.29 W/m^2 (bedroom)*
Equipment Sensible Gain: *126.3 W/m^2 (kitchen) + 6.34W/m^2(bedroom)*

The results show an average difference of 6K between the bedroom and the outdoor resultant temperature. The peak indoor temperature which reaches almost 38°C while outdoor relative humidity is 80% during the occupancy hours for lunch, demonstrates the high level of discomfort a slum resident experiences. Throughout the year the base case is out of comfort for 43.3% of the time, while the external temperature is out of comfort range only for 16.1%.

Therefore, the analytic work focused on improving the existing unit aimed at decreasing the resultant indoor temperature. Improving the roof specifications, varying the fenestration and changing the materiality have the highest impact (Fig. 8). Only these three cases (i.e Case 1, 4and 5) have been discussed below. Other cases (2,3,6-10) are depicted in the images for a better comparative analysis and understanding.

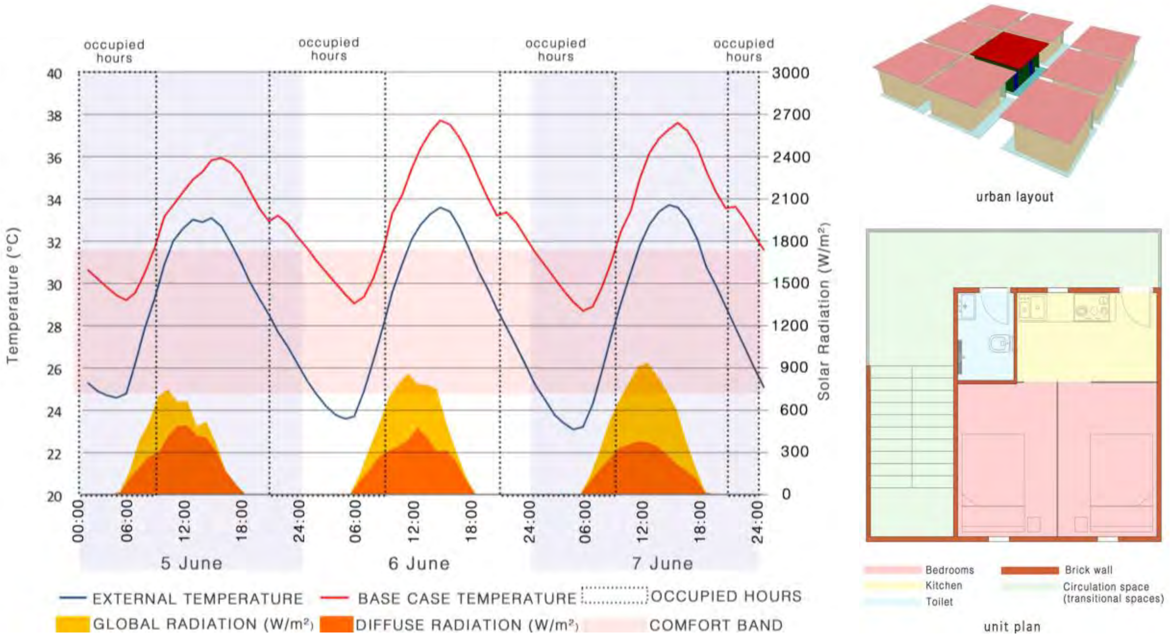

Fig. 4. Resultant temperature of base case for 3 typical summer days. TAS model layout for base case (right).

Strategic improvements of the base case:

Case 1- Improved roof: Figure 5 indicates that the roof surface receives the maximum solar irradiation. Hence the first intervention was to replace the initial clay tile by concrete slab with a layer of damp-proofing and additional solar panel installation (weighted U-value = $0.2W/m^2K$)

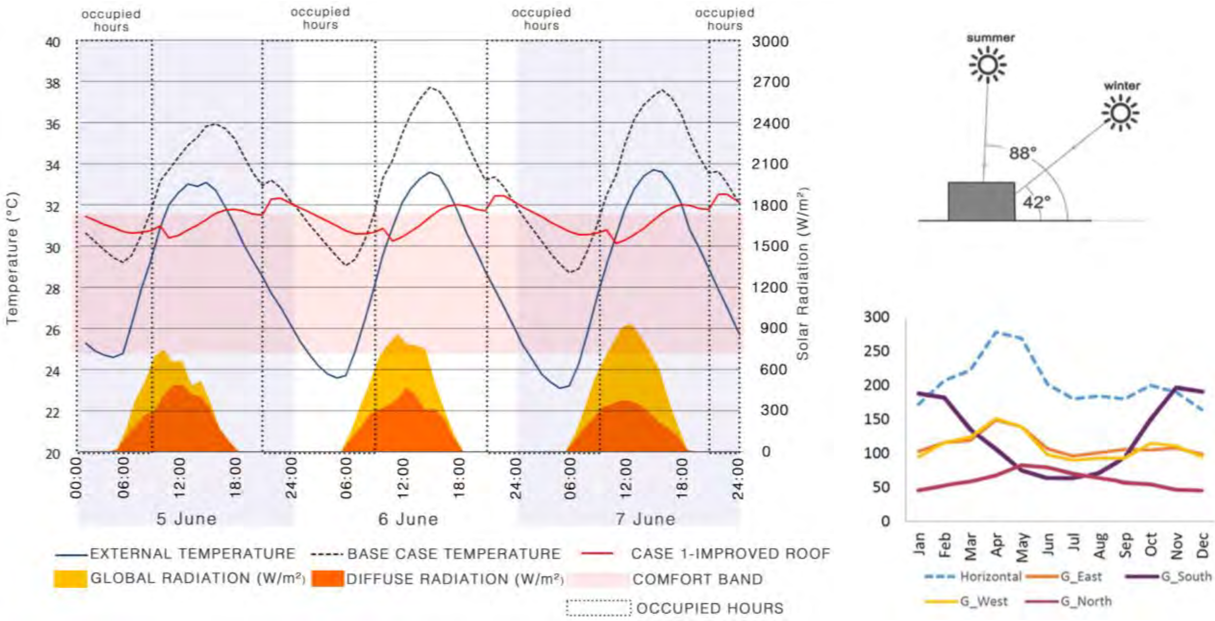

Fig. 5: (a) Resultant temperature for improved roof scenario. (b) Annual solar radiation Kolkata (right).

The TAS simulation for the typical summer days shows a significant drop in the resultant temperature in the bedroom and is more consistent throughout the day. Case 1 registered 5K lower resultant temperature than the base case during the peak hours of the day and 2K higher temperature during the minimum temperatures at night.

Case 4 - C3+fenestration change: The fenestration sizes were increased to improve ventilation. The fenestration to floor ratio was increased from the initial 9.9% to 43.4% showing a huge drop in air temperature. The bedroom is within comfort range throughout the day figure 6.

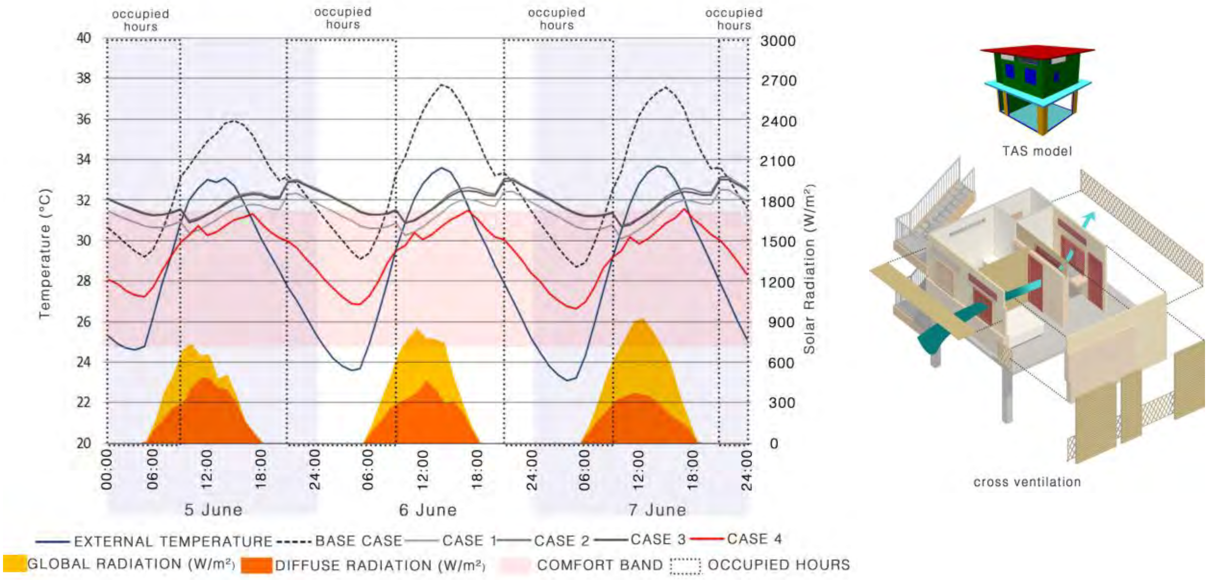

Fig. 6. Resultant temperature for improved fenestration.

The resultant temperature has dropped by 1K during daytime peak hours and by 4K at night-time. Thus, closing the window during peak hours helps benefitting from the effects of high thermal mass of the unit. At night, opening all the windows facilitates night time cooling, thereby converting it into a low thermal mass unit. This step was one of the most important interventions. The windows are louvered to block the abundant diffuse solar radiation and allow only ventilation during the day.

Case 5 - C4+all material change: The effect of replacing the generic brick construction with all the vernacular materials identified during fieldwork was studied. A series of tests were undertaken to deduce the size and height of each material panel that will be implemented on the unit, Figure 7. The final configuration of the materials to be used as the envelope had a similar performance as the existing brick one. Nevertheless, it is still worthwhile to take up this intervention because of the following reasons:

1. Energy consumption in a cubic meter of CSEB (compressed mud blocks) can be 5 to 20 times less than a generic brick and mortar construction (Auroville, 2015), (BMTPC, 2015).
2. The pollution emission for CSEB blocks will also be 2.4 to 7.8 times less than fire bricks (Auroville, 2015).
3. The unit envelope is constructed with locally available materials and semi-skilled labour (in this case the residents themselves, the majority of which are familiar to these materials), almost without transport.
4. Cost estimates for the wall envelope made of wattle and daub, bamboo and CSEB blocks can be 46% cheaper than traditional brick construction.

5. Since these local materials mentioned above are familiar to slum residents, there is the opportunity for the project finances to be used on people rather than the industry (which would have been the case had they been using brick and concrete).

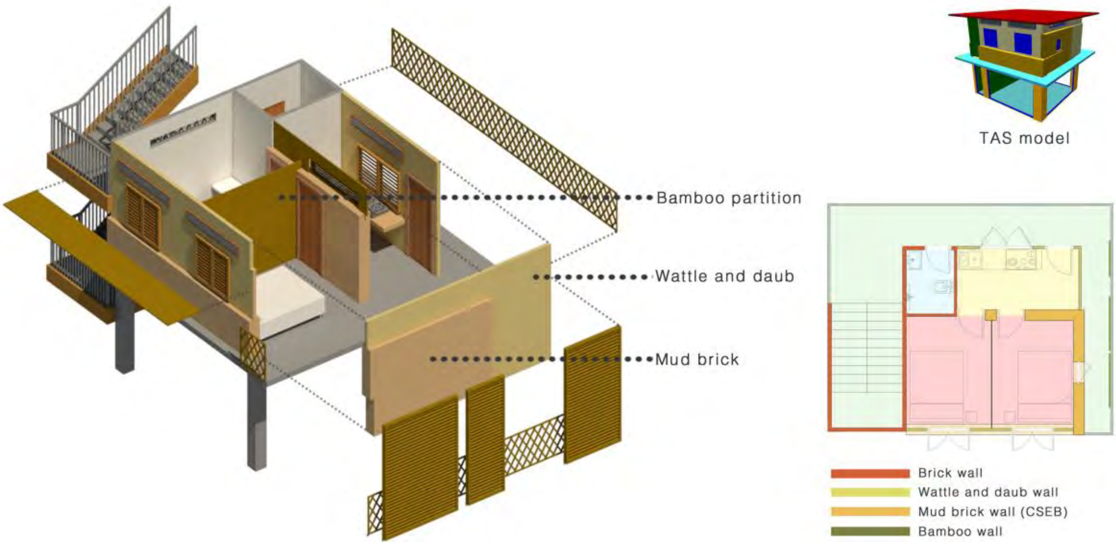

Fig. 7. Replacing traditional brick and mortar with local material panels for ease of construction.

Annual percentage of discomfort hours:

While testing the different cases, the percentage of hours when the indoor resultant temperature was beyond 31.6ºC (upper limit of comfort band using Nicol's equation for adaptive comfort) was also checked for the entire year. Fig. 8 shows how the percentage of discomfort hours have been reduced from 43.3% (base case) to 10.6% (final case), well below 16.1% (external temperature). Furthermore, if the percentage of discomfort hours is considered only during occupancy hours, it decreases to 3.25% (11 days approx.). This can be easily mitigated with the use of mechanical fans at a speed of 0.5m/s.

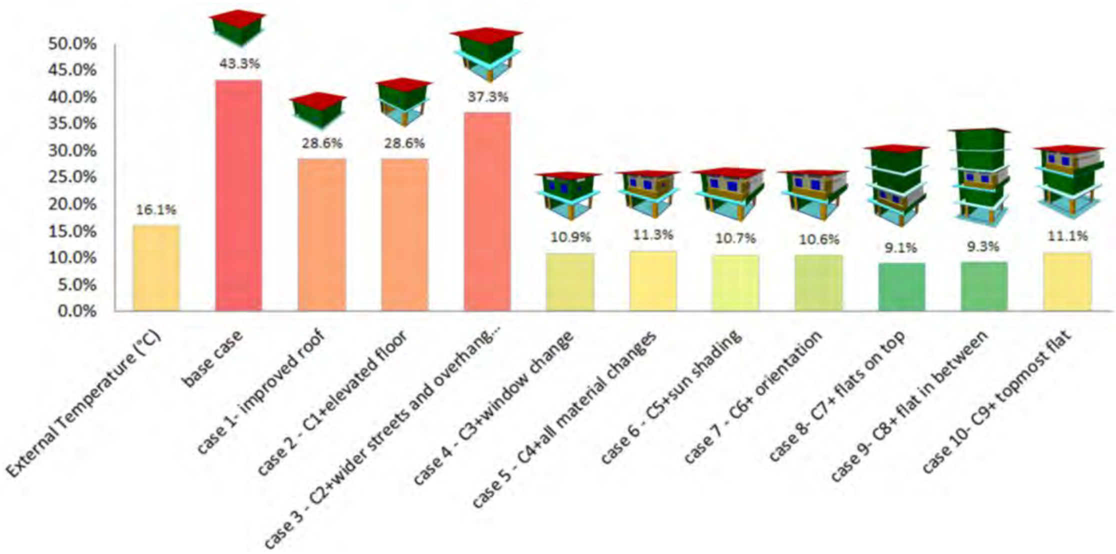

Fig. 8. Comparison of the percentage discomfort hours of all the interventions for the entire year.

Conclusions:

Extensive research, including fieldwork and analytic studies were part of the design process aiming at housing urban slums residents in habitable, sustainable and economically viable communities (Fig. 9) in the hot and humid climate of Kolkata. The study showed that free-running units providing comfortable indoor resultant temperatures throughout the year can be achieved combining new technologies with traditional strategies including low-cost local materials, such as mud bricks, bamboo and wattle and daub. The proposed unit was designed to benefit from high thermal mass materials during the day to mitigate the high incident solar radiation and from low thermal mass materials during the night to allow a better effect from the cool breeze flowing indoors through the large fenestrations, thus facilitating the dissipation of the internal heat gains. Analytic studies showed that the proposed unit would thermally perform very similarly if the use of brick was replaced by the low-cost local materials, but worthwhile due to massive economic and environmental benefits, including the possibility to being built by the owners.

Fig. 9. Future replication of the prototype unit in building and urban scale.

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Defining the Right Balance between Passive and Active Systems in an Appropriate Housing Design

Achilles Sophia Madhi Gnanaprakasam[1] and Guillermo Guzman Dumont[1]

[1] Faculty of Engineering, University of Nottingham, Nottingham, United Kingdom

Abstract: Increasing concerns over global warming, energy shortage and poor occupants comfort have led to the implementation of energy efficiency standards worldwide. Passivhaus standard is an active approach, widely implemented in Europe, is now being expanded across the world, including hot and humid climates. Considering its complexity and high implementation cost, a more affordable system which integrates both passive and active design strategies are in demand for hot developing countries, but hasn't developed or implemented enough. In India, especially in Chennai, the usage of air conditioning in a housing sector is enormous, leading to high energy consumption in the present day context with respect to poor ventilation and inadequate construction techniques. Due to economic and cultural reasons, the European approach might not be a suitable solution for India, raising the question of good living quality with low energy houses that responds to future needs. By considering these aspects, this research identifies a suitable passive design strategy and a building construction technique, based on the comparisons of thermal and energy simulations of a passivhaus (Nottingham H.O.U.S.E, a case study building designed for both hot-humid and then cold climate), a present day house and a traditional house under Chennai climate.

Keywords: Energy Efficiency, Thermal comfort, Natural ventilation, Passivhaus, Dynamic simulation

Introduction

The awareness and the execution of energy efficiency standards have become a necessity in today's building context, due to the uncompromising environment. Despite, a recent baseline study for commercial and residential building found that energy consumption due to space cooling and lighting in residential buildings accounts for one third of total energy consumption in India (Bhatt, et al., 2005)

Regarding this uncertainty, the Energy conservation act introduced by Indian government commenced the Energy Conservation Building code (ECBC) in 2007 for energy efficient buildings (BEE, 2011). However, this code largely applies to the air-conditioned buildings with 1000 m² floor areas, particularly for commercial and office buildings. Besides, the other voluntary green building rating systems such as Indian green building council (IGBC) green homes, AaDarsh's SVAGRIHA which encourages the energy efficiency in residential sector have not been reached properly to the middle class families who seemed to be majority Indian population (Rawal, et al., 2014). Meanwhile, regardless to the introduction of passivhaus (also known as passive house) concept in a cold climate assured maximum thermal comfort and indoor air quality with significant decrease in primary energy demand (Feist, et al., 2005). However, the application of passivhaus, which has not been fully explored with respect to hot and humid climates, might or might not perform better under Chennai, a hot and humid climate. Or else, can eventually contribute some ideas in terms of comfort and energy efficiency in near future.

Relying on this observation, the thermal and the energy performance of Nottingham H.O.U.S.E, the typical present day and traditional house of Chennai has been studied and the results of these three houses (figure 1) has been distinguished in a way, a suitable passive design strategy and a construction method can be incorporated in future for a healthy and efficient housing in Chennai.

Figure 1. The three different houses dealt in the research

Concept of Passivhaus

Passivhaus is a voluntary standard derived from building physics, which ensures comfort, cost effectiveness and energy efficiency (Passipedia, 2015). In order to achieve the passive house standard, the required heating/cooling demand should be 15 -10 kWh/(m²yr), primary energy usage should be 60 - 120 kWh/(m²a) and the airtightness including air changes should be n50 = 0.6/h (Feist, et al., 2005). However, these three requirements can be attained through various key principles such as high performing windows, Airtightness, Thermal Insulation, Avoidance of thermal bridge and Ventilation with heat recovery (Passipedia, 2015).

Moreover, the passivhaus concept that was developed in central and northern European climates has been adapted recently to various climatic conditions including very hot climates that totally differ from Germany and Austria (Schnieders, et al., 2015). similarly , a recent research, "Passive houses for different climatic zones" carried out by Schnieders, et al., (2015) under six climatic zones including hot and humid climate, implies that primary energy demand and peak daily average load assumed for ideal heating or cooling system seemed to hold indoor temperatures in an inner comfort range most of the time.

Passivhaus: The Nottingham H.O.U.S.E

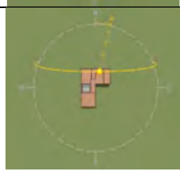
The Nottingham H.O.U.S.E, a family oriented two storied housing (figure 1) that was built with passivhaus standards was initially a diploma and master's studio design project, designed within a master plan that involved a Zero Carbon community, to meet the specifications provided by the Solar Decathlon Europe competition. In addition, the Nottingham H.O.U.S.E which is located near creative energy homes at Green Close in University Park campus, Nottingham was designed for both Madrid (hot) and Nottingham (cold) climate respectively. However, a difference in the usage of double height spaced dining area that has a roof light for ventilation, varied according to that particular climatic zone, to provide cooling in Madrid climate through Passive down draught evaporative cooling system and to naturally ventilate through stack effect in Nottingham (Guzman, 2012).

Figure 2. The Nottingham H.O.U.S.E

Climate analysis (Madrid and Nottingham with Chennai Climate)

The comparison table 1 shows that, the south facade of the Nottingham H.O.U.S.E is the most exposed facade throughout the year under Madrid, Nottingham and Chennai climate respectively. However, south façade receives high solar radiation with respect to Chennai; also the north façade seems to be exposed most of the year (summer and equinox). Besides, the average temperatures shows the clearly defined temperature range during seasonal variations for Madrid and Nottingham, whereas Chennai has steady temperatures through the entire year with a daily temperature swing between day and night of 8.3°C.

Table 1: Comparison of Nottingham H.O.U.S.E with respect to climatic zones

Location	Summer Solstice : 12.00	Equinox : 12.00	Winter Solstice : 12.00
Madrid, Spain: Latitude: 40.5° N. Average Temperatures : summer Solstice - 20.6°C, Equinox- 20.0°C, winter Solstice - 5.8°C			
Nottingham, UK: Latitude: 52.95°N. Average Temperatures : summer Solstice – 14.2°C, Equinox- 12.9°C, winter Solstice – 5.6°C			
Chennai, India: Latitude: 13.08° N. Average Temperatures: summer Solstice - 29.9°C, Equinox- 26.4°C, winter Solstice - 25.4°C. Daily temperature swing: 8.3°C			

Housing in Chennai

Many transformations are seen from early century to this era, with respect to housing in Chennai due to various reasons including westernization, population explosion, inadequate space and technological developments.

The Present day Housing

The resulted present day houses of middle class families are mostly compact in size that has single side ventilation and sometimes cross ventilation is achieved if the doors were also kept opened. In addition, a typical present day single storied house consist of a living area, kitchen, a toilet, two bedrooms and utility as shown in figure 2.

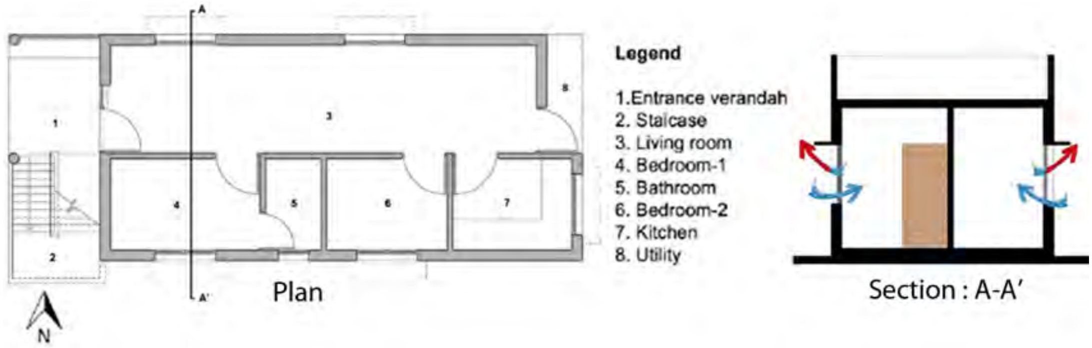


Figure 3. The Typical Present day House

The traditional housing

The traditional houses that were built around 19th century in Chennai had passive cooling strategies that responded to regional climate. For instance, Venturi effect was used to suck the hot air out with the help of mutram, an open to sky courtyard. Additionally, the deep verandahs with sloped roof inside and outside the houses were used for shading in summer. A typical traditional house (figure 3) that has been used for this research is a single storied square house that has mutram and columned inner verandahs. The house also consists of a front verandah with seating called otta that faces east direction and other services that includes toilets at the backyard (Desai, et al., 2012). Furthermore, these houses are usually constructed with red oxide flooring, country tile roofing, Burma teak rafters and lime plastering (Iyer, 2011).

Figure 4. The Traditional House

The Research Methodology

A significant method that compares the building performance of a passivhaus (Nottingham H.O.U.S.E, a case study building) with a typical present day and a traditional house of Chennai has been dealt in this paper. Moreover, the study of each house has been divided two parts namely, thermal and energy analysis. In which the thermal analysis under several cases has been carried out with Apache dynamic simulations from IESVE (integrated environmental solutions – virtual environment) software and the basic energy calculations for each house has been carried out with Sefaira architecture software. Moreover, the thermal simulation cases and general assumptions used for all the three housing assessment are as follows.

Thermal simulation cases

The first set of simulations were carried out using natural ventilation for throughout the year and the second set of simulations were done using natural ventilation but only for the summer period (April, May, June). However, with respect to Nottingham house, the second set of simulations was carried using roof light kept opened continuously to check ventilation in summer.

General Assumptions for thermal and energy simulations

- *Weather profile*: Madras/Minambakkam (Chennai) weather data was used from ASHRAE (climate zone 1) design weather database V 5.0 in IESVE.
- *Comfort and Energy*: Indoors with 18°C to 29°C were considered based on comfort zone provided for developing countries with hot climate by Givoni, (1992) and the passivhaus standards for primary energy cooling demands (Feist, et al., 2005).
- *Construction used:* Building components with respect to U-values (W/m² K) are given in table 2.

Table 2. U-Values of construction components

Types	External walls	Internal walls	Floor	Roof	Windows
Nottingham H.O.U.S.E	0.09	2.46/1.38/1.79	0.11	0.12 (internal ceiling-1.08)	0.5
Present day House	2.44	1.75	1.13	3.35	5.17
Traditional House	1.35	1.50	1.13	1.50(Slope roof)	5.17

- *People gains*: Occupancy per house was considered four with maximum sensible gain of 70 W/person and maximum latent gain of 45W/person.
- *Lighting gains*: Low energy florescent lights were considered for living (0.6W/m²), bedroom (0.25 W/m²), kitchen (0.6 W/m²) and dining room (0.6 W/m²) for both maximum sensible heat gain and power consumption inside Nottingham H.O.U.S.E. Nevertheless, Lighting gains with respect to present day house and traditional house were assumed 8 W/m2 for both maximum sensible heat gain and power consumption.
- *Equipment and appliances gains*: These gains vary according to kitchen and living with respect to each house and their usage. For Nottingham H.O.U.S.E, the gains were 60 W/m² and 5 W/m² respectively. For Present day house, they were 1.3KW and 2.5KW respectively. However, With respect to traditional House, the gains were considered as 0.69KW and 0.5KW respectively, since only fridge and TV was assumed.
- In addition, the variation profile of all the above given gains has been considered based on the daily activities undertaken by all the occupants in each house for different hours of time.
- *Infiltration*: The infiltration rate of 0.6 ACH was considered for Nottingham H.O.U.S.E, since it is an airtight building that follows passivhaus standards. However, the infiltration rate for present day and traditional house were assumed as 1 ACH.

– *Ventilation*: Natural ventilation rates were assumed as 6 ACH based on the Indian building standards given for functional requirements of buildings. An effective opening of 90% based on the daily activities of the occupants has been considered for windows.

Results

Table 3. Comparisons of Thermal and Energy performance of Houses

Description	 Case study building(Nottingham H.O.U.S.E)	 Present day house	 Traditional house
Thermal comfort (Thermal simulation - Case1)	27.30%	45.38%	60.60%
Summer comfort with roof light kept opened continuously (Thermal simulation -Case 2)	13.60%	10.78%	25.40%
Ventilation strategy used	Roof light opening (stack effect) + cross ventilation	Single side ventilation	Courtyard with stack effect + ventilation
Thriving Ventilation strategy that actually showed consistent increase thermal comfort	✓	✗	✓
Increase in comfort with respect to infiltration alone (without ventilation)	✗	✓	—
Primary energy demand	85 kWh/ (m^2 a)	210 kWh/ (m^2 a)	112 kWh/ (m^2 a)
Primary energy demand that satisfied low energy requirement (120 kWh/ (m^2 a))	✓	✗	✓
Building thermal properties and glazing typology used	Well insulated, low U-values (table 1) Triple glazing	Un-insulated, High U-values (table 1) Single glazing	Un-insulated, standard, U-values (traditional method) (table 1) Single glazing
Low energy demand with respect to building thermal properties and passive strategy used	✓	✗	✓
Specific Cooling demand	34.3 kWh/ (m^2 a)	70.1 kWh/ (m^2 a)	58.5 kWh/ (m^2 a)
Specific Cooling demand that satisfied low energy requirement (15 kWh/ (m^2 a))	✗	✗	✗
The major gains that drives the cooling demand	Solar gains from south, north and east facade	Wall and roof conduction and solar gains from south facade	Wall and roof conduction
Reason behind the high gains	No external shading device	No insulation Improper shading devices	No insulation

All the three types of houses have their unique style of design strategy and construction used. However, it is important to consider a right set of building elements (u-values, infiltration) including passive strategies to develop a house for a comfortable living in a particular climate without affecting the environment. The comparison table 3 based on comfort temperature range (Givoni, 1992) and the specific energy usage (Feist, et al., 2005) helps in defining each house, its advantages and disadvantages with respect to their specific features that responds to the Chennai climate.

Conclusions and Discussions

From the comparisons (table 3), it can be understood that the traditional house provides more percentage of comfort hours with respect to case 1 and case 2 than the present day and Nottingham H.O.U.S.E. In addition, it can be seen that, the roof light (stack effect ventilation strategy) opening in Nottingham H.O.U.S.E with respect to summer helps in increasing the thermal comfort, compared to present day house that has single side ventilation. From this understanding, it can be assumed that the combination of cross ventilation with stack effect/ venturi effect as given in Nottingham house and traditional house, proved to be a better ventilation option. However, a very low infiltration rate is not suitable for a house in Chennai with respect to passivhaus (Nottingham house) that has more airtightness leads to the very low comfort, whereas present-day house with standard infiltration rates has shown better thermal comfort.

Particularly, the building thermal properties used in Nottingham H.O.U.S.E and traditional house seemed to help in lowering the energy demand of the houses, whereas only increase in comfort through infiltration (without ventilation) is seen in present day house. Still, cooling demand seemed to be uncompromising in all the houses due to unwanted heat gains, which can be reduced by adding good levels of insulation and proper external shading devices(particularly on south side).

Developing mega cities like Chennai that faces major issues such as space constraints, increase in pollution and the high land values creating unaffordable conditions for an efficient living can be dealt with few considerations that this research seemed to contribute. In addition, this research contributes a passive design ideas that can be adapted in a national spectrum in most of the hot-humid urban and rural areas in India Originally, an integrated stack effect ventilation with cross ventilation within any house (as provided in Nottingham H.O.U.S.E) seemed to decrease space constraints and increases comfort. Furthermore, insulated building components accompanied by standard infiltration that coincides with the climate serves both thermal comfort and low energy consumption.

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Contribution to thermal comfort of walls waters supplied by a rainfall collection system in the Metropolitan Area of Mexico City

María Yazmin Pinacho Gonzaga[1], Arturo Lizardi Ramos[2], Clementina Rita Ramírez Cortina[3] and Edwin Israel Tovar Jimenez[4]

[1] University Autónoma Metropolitana, Campus Azcapotzalco, Mexico City, Mastery in Bioclimatic Design, al2153801311@azc.uam.mx
[2] University Autónoma Metropolitana, Campus Azcapotzalco, Mexico City, Mastery in Science, arlr@correo.azc.uam.mx
[3] University Autónoma Metropolitana, Campus Azcapotzalco, Mexico City, Doctorate in Process Enginering, crrc@correo.azc.uam.mx
[4] University Autónoma Metropolitana, Campus Azcapotzalco, Mexico City, Mastery in Bioclimatic Design, orieste@gmail.com

Abstract: In this work, finite element method was used, trough the software COMSOL Multiphisics ®, to analyses the thermal performance of a theoretical space whose main facade wall, facing south, is equipped with a glass water tank, to maximize the thermal storage and thermal mass effect. The climatic data base was incorporated from the Meteonorm® software, to which real climate data was incorporated from the National Meteorological Service (CONAGUA,2000) station of Azcapotzalco, in Mexico City, to perform the required interpolations. The main parameters used in this study were outside dry bulb temperature and solar irradiance. The inside temperature conditions were evaluated with the comfort model of Aulliciems and Zokolay (1997).
The 3D model system consists of a rectangular spaced composed of an isothermal vertical water wall and all other surfaces considered as adiabatic. The south water started with an ambient temperature *Ta* and the others surfaces at a temperature *Tf*; fulfill condition *Ta* > Tf, causing the heat transfer process. The study emphasizes the pertinence of implementing a thermal wall supplied by a rainwater harvesting system.

Keywords: Water thermal storage wall, Numerical simulation, Thermal comfort

Introduction

The term “Water walls” refers to the use of water as thermal mass in passive solar houses for heating and cooling (Bainbridge, 2005).
The actual configuration of a water wall system will depend on the location and weather condition for its application. The locations of some cases with this strategy, cover only a few places: Australia, Europe, India, Turkey, China and Africa (Ting Wu et al, 2016). Water has a high heat capacity to store sensible heat (Cengel et al, 2012) (Weiliang et al, 2012). These systems have a thermal mass effect, and considering that the thermal mass is highly effective for the climate of Mexico City, this study will determine the appropriate parameters for the water, air layer and for the whole wall thickness. The current document establishes a theoretical space that uses a thermal storage water-wall to obtain the most efficient system configuration based on temperatures and solar irradiance.

For daily amplitude of Mexico City, Mahoney (Koeningsberger et al, 1977) recommends the use of massivity above 10 °C, however, Evans (2000) indicates that this strategy is convenient from 8 °C. Mexico City presents a daily average amplitude of 11.5 °C, the minimum in September of 8.5 °C and a maximum in March of 14.1 °C. Docherty et al (1999) define three mass effects: Winter mass, Summer mass and Summer mass with night ventilation. In the case of Mexico City, the lower limit of winter comfort is 20.3 °C; for a temperature in January of 13.8 °C and a daily amplitude of 13.5 °C; it means that limit of the effectiveness of the strategy of winter massivity occurs above 14.9 ° C (20.13 - (0.4 x 14.3) = 14.9 °C).

Comfort Zone

Climatic data was analyzed according to the annual characteristics of temperature, relative humidity, solar radiation and wind. The reference parameter to analyze the temperature is the comfort zone, which is defined from the Neutral Temperature (Tn), using the linear equation of Auliciems (Auliciems et al, 1997):

$$T_n = 17.6 + 0.31 T_{med} \tag{1}$$

Where T_n is the neutral temperature and T_{med} is the annual mean temperature.
This adaptive comfort model proposes to apply a thermal amplitude of ± 2.5K on the Tn for annual periods. In this way, the Upper and Lower Limits of the Comfort Zone (ZCs and ZCi, respectively) for Azcapotzalco, are defined as follows:

T_n = 17.6 + 0.31 (16.7) = 22.77
ZC = 25.3 ° C; ZCi = 20.3 ° C

Water management

The use of technology that uses rainwater is based on rainwater harvesting systems that ensure the water supply during the rainy months, allowing its storage to be used even during the dry season. Among the elements that integrate a system of capture and exploitation of rainwater are the surface of capture, conduction, water treatment system, storage and distribution. The proposal that is mentioned in the present work is the use of water wall for temporary storage of this rainwater and to integrate it to the architectural design of a wall, at the moment it has not been approached like a temporary storage system that serves simultaneity as a thermal regulator in the built-up space.

Description of this research

The configurations and dimensions of the model are determined according to the model of Figure 1. Dimensions are set at L = 3.60, A = 3 m and H = 2.40. The floor, the ceiling and the three walls are isolated except the south side. The dimensions established correspond to the statistically most common space of a bedroom, with high thermal comfort needs. This type of composition allows to know the effect of the water wall system and its influence on indoor temperatures. The south wall is used to store and release heat. The water wall has a width of 0.07 m, and the water use is 0.168 m^3 and the air layer is 0.05 m.

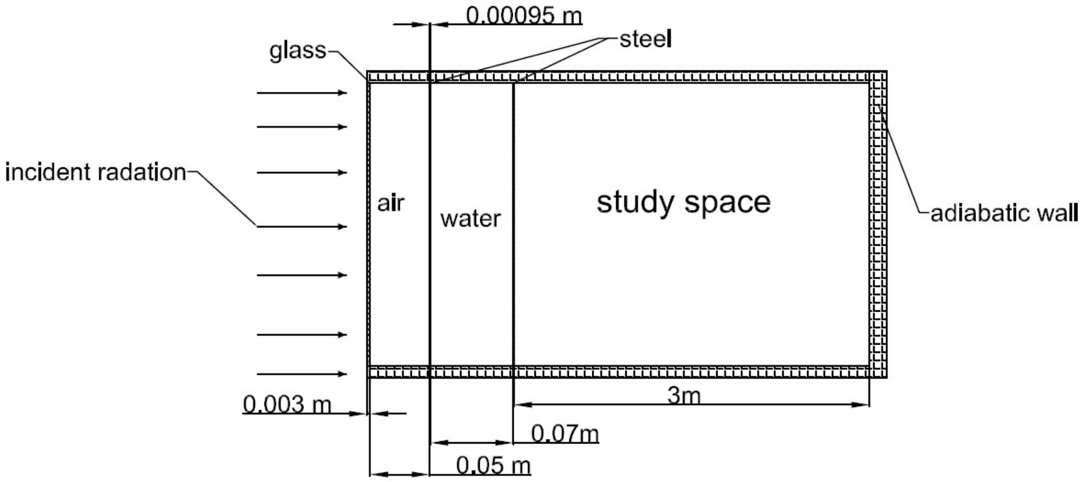

Figure 1. Sketch of a water wall.

Mathematical Approach

The physical model consists of a closed space of height H in the "Y" axis, long L in the "X" axis, and depth "Z", the water wall system starts at an initial temperature Ti, that varies over time. The upper and lower surfaces are thermally insulated, 2 configurations are handled: variation of wall thickness of water and variation of air layer.

In the formulation of convective heat transfer problems (equation 2) it must be recognized that in a moving fluid the heat energy is transported both by conduction (equation 3) and by the movement of the fluid, a body emits radiant energy with a speed given equation 4, but at the same time absorbs radiation; If this did not happen, the body would at some time radiate all its energy and its temperature would reach absolute zero. The energy a body absorbs comes from its surroundings, which also emit radiant energy.

$$Q_{conv} = H\, A_S(T - T_\infty) \tag{2}$$

Where: Q_{conv} is convection heat transfer rate, H is factor of convection, A_S is the area involved in the heat transfer process, T is the system temperature and T∞ corresponds to the ambient temperature.

$$Q_{cond} = k\, A\, (\frac{\Delta T}{\Lambda X}) \tag{3}$$

Where: Q_{cond} is conduction heat transfer rate, k is the thermal conductivity coefficient, $\frac{\Delta T}{\Delta X}$, is the temperature gradient

$$Q_{rad} = \varepsilon\, \sigma\, A\, (T_a^4 - T_\infty^4) \tag{4}$$

Where: Q_{rad} is radiation heat transfer rate, σ = 5.67x10-8 W/(m^2K^4) is the Stefan-Boltzman constant, and ε is a radiative property of the surface called emissivity, its values vary in the range 0 <ε <1, is a measure of the efficiency with which the surface emits radiant energy, depends on the material (Inzunza, 2009).

Methodology

To solve the equations of radiation, temperature, as well as the natural external convection equation governing the system together with the boundary conditions, the finite element method was used through the software COMSOL Multiphisics® Modeling Software 5.2 (2017). For these, the following methodology was used:

a) The type of analysis is selected in the software, in this case 3D model.
b) The geometry to be analyzed is drawn and the border elements are generated. In this case, the cavity was dimensioned with a height of 2.4 m, width 3.60 and a depth of 3 m. the system is formed by different layers: 3mm glass; air in different dimensions, 0.0095 m steel sheet, water which vary the thicknesses of 5 cm and 10 cm respectively; and another steel sheet 0.0095 m thick.
c) Six combinations of air and water thickness were analyzed: 1) air 5, water 5cm; 2) air 5, water 7cm; 3) air 5, water 10 cm; 4) air 10, water 5 cm; 5) air 10, water 7 cm; 6) air 10, water 10 cm.
d) The initial values are entered, which start with a temperature of 7 °C, as this is the outside temperature at the beginning of the simulations.
e) The boundary conditions are introduced and different temperature and radiation functions are handled for each day, which correspond to the external conditions to which the system is subjected, so that the software makes a variation of temperature between the walls of the cavity.
f) The interfaces solved by the program were heat transfer by radiation, heat transfer in fluids, heat transfer in solids and heat flow.
g) A cutting plane is created in the X axis, Z coordinate Y = 1.8 (figure 2), the above to export the position data to the interior of the cavity with their respective temperatures; To perform the unidirectional flow temperature distribution graph in a two-dimensional plane, a cut line is created on the X, Y (0.1549,1.2) and (3.1549,1.2) (figure 3)

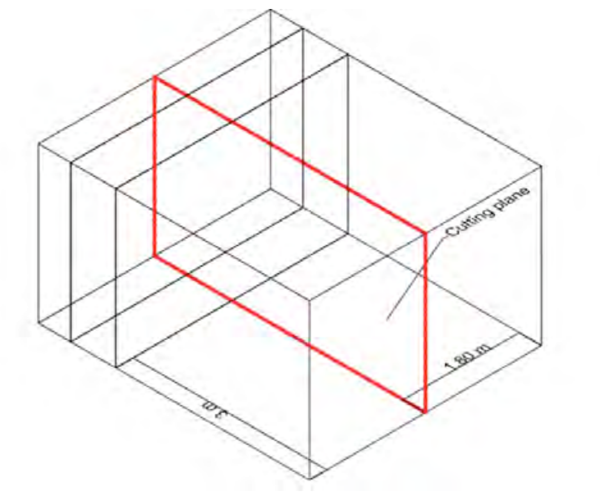

Figure 2. Cut plane in axis X, Z.

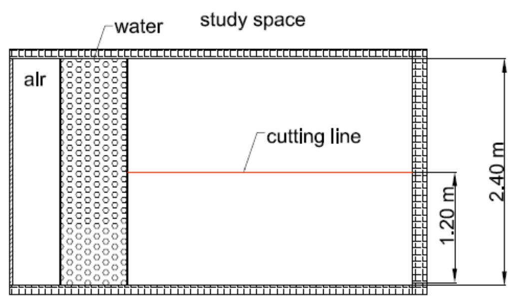

Figure 3. Cut line in axis X, Y.

Result and discussion

The interior temperatures per hour for a week in January are shown in Figure 4, where the horizontal lines correspond to the established comfort range, and the curves represent the variation of the interior temperatures as the thickness of the water wall system changes.

A total of 168 hours was simulated, these hours represent the coldest week of the year in Mexico City. The minimum ambient temperature is 3.8 °C plotted at 6:00 am, and

the maximum of 22.5 °C is at 15:00 pm, the temperature oscillation is wide, reaching up to 19 °C. The outside temperatures are located within the comfort zone 5.35% of the time, which means that 95% of time in the winter season requires spaces efficient to gain heat.
It is observed that the behavior of the heat flow between the exterior and interior space was normalized after the first 125 hours, because the test starting temperature was a theoretical temperature that was proposed equal to the outside for the same hour (7 ° C).
In order to establish the most suitable dimension for the water and air layers of the water wall, the data are taken into account after the hour 126. From this interval, the behavior of the interior temperatures is cyclical, allowing comparison of the inner and outer thermal amplitudes.

The parameters to qualify the good performance of the walls are: development within the comfort zone; close to the neural temperature; lower decrement factor; and lower temperature amplitude.

The six-proposed water-wall systems reduce the internal temperature by up to 14 °C compared to the outside temperature. They also reduced the oscillation of internal temperatures by up to 13 °C compared to the outside temperatures.

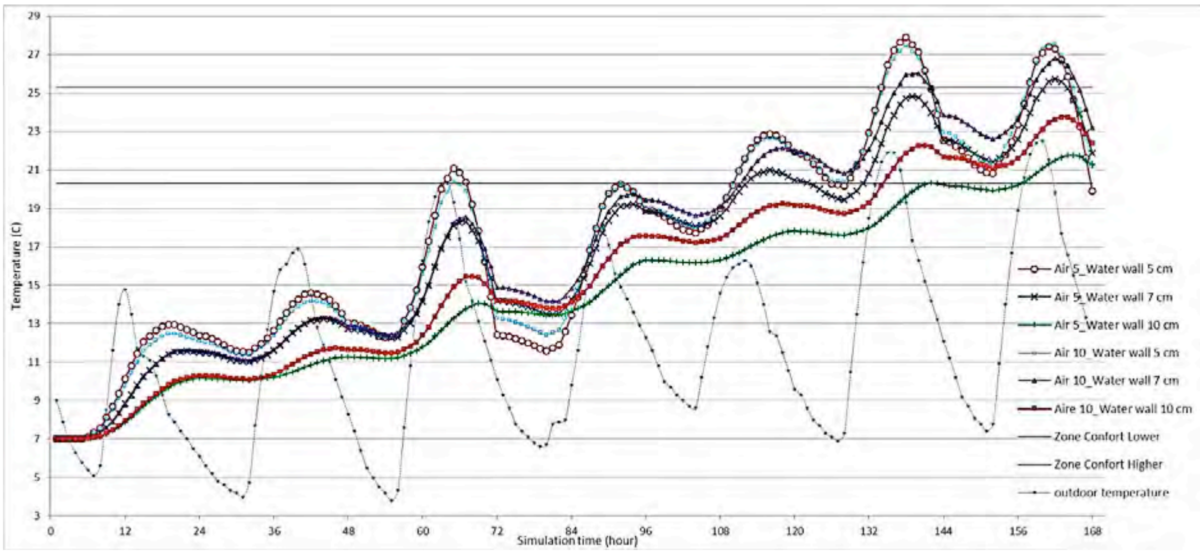

Figure 4. Behavior of indoor temperatures

Table 1. Behavior of interior temperatures according to their dimensions

System	Air gap (cm)	Water gap (cm)	Indoor amplitude (C)	Outdoor amplitude (C)	Decrement factor DFs	Time inside the comfort zone (hour)
1	5	5	7.50	15.1	0.49	16
2	5	7	4.3	15.1	0.28	20
3	5	10	1.82	15.1	0.12	12
4	10	5	6.37	15.1	0.42	17
5	10	7	4.20	15.1	0.27	17
6	10	10	2.64	15.1	0.17	24

According to the results shown in Table 1, the combination of air layer and water layer dimensions that provides the best performance of indoor temperatures are the wall of 10 cm of water and 10 cm of air (figure 5,6,7 y 8).

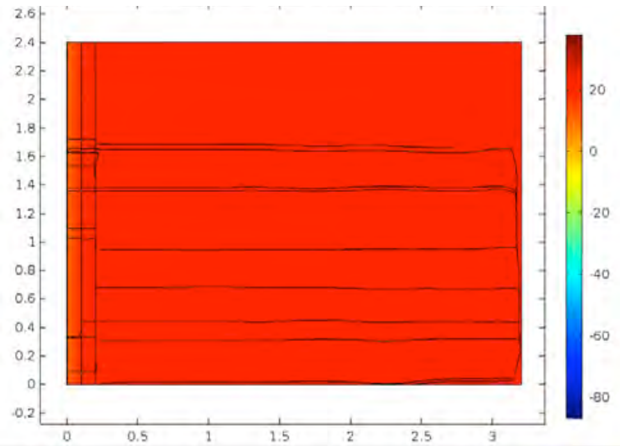

Figure 5. 8:00 h, water 10 cm y air gap 10 cm.

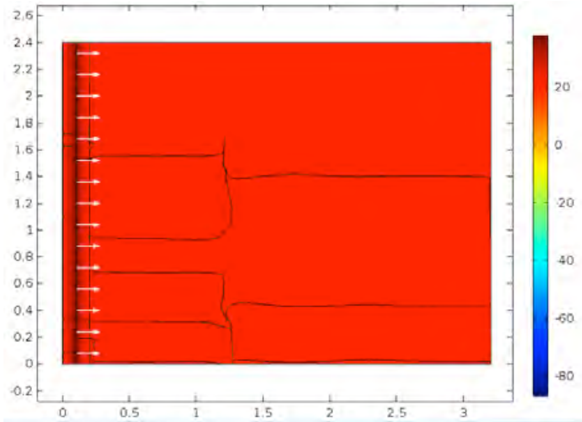

Figure 6. 14:00 h, water 10 cm y air gap 10 cm.

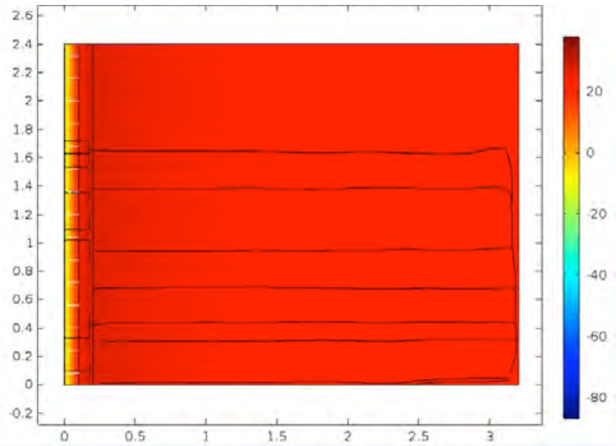

Figure 7. 19:00 h, water 10 cm y air gap 10 cm.

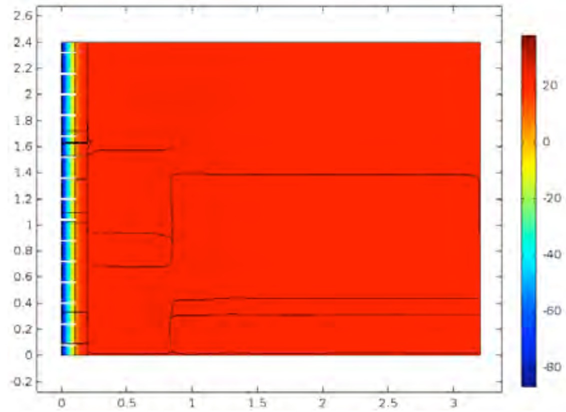

Figure 8. 12:00 h, water 10 cm y air gap 10 cm.

Conclusions

According to meteorological data and based on bioclimatic strategies, in Mexico City it is recommended the use of thermal mass, mainly in winter. According to the theoretical space evaluated with a thermal storage based on a water wall system, the following conclusions are:

The effect of air is not significant when having small water thicknesses (5-7cm), however, by increasing the wall thickness up to 10 cm, the effect of the air layer becomes more visible, staying in the greater comfort zone (air 10 and water 10) or less time (air 5 and water 10).

The indoor thermal amplitude is smaller (1.82 ºC) with the configuration: air 5 – water 10, and with a surface decrement factor (DFs) about 0.12; which represents the ratio of the thermal amplitude of the inner and outer surfaces of the wall. The lower the DFs, the better the performance of the construction system. However, this configuration, despite having lower DFs, offers comfort conditions only for 12 hours, compared to the wall water (air 10 - water 10), which remains within the comfort zone 24 hour with a DFs of 0.17.

The heat storage effect of the water wall for the coldest week of the year can increase indoor temperatures, up to 5 °C above maximum outdoor temperatures.

In winter, the water wall can increase the required heat load during night and day, regulating temperature until reach the comfort conditions. This technique of thermal storage fulfills the objective of a bioclimatic building for this climate, which is to reduce the daily amplitude of temperatures.

Materials, thickness of the different building systems and their thermophysical properties, (conductivity, density and heat capacity) determine different scenarios of heat transfer within a building. Therefore, different interior thermal conditions can be generated; spaces with pleasant temperatures or those with overheating or overcooling. An appropriate design must be based on the understanding of the properties of materials and constructive systems to create comfortable and healthy environments.

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New method for choosing design strategies for sustainable buildings

Andrea Invidiata[1] and Enedir Ghisi[2]

[1]Federal University of Santa Catarina, Department of Civil Engineering, Laboratory of Energy Efficiency in Buildings, Florianópoli, SC, 88040-900, Brazil, a.invidiata@gmail.com.
[2]Federal University of Santa Catarina, Department of Civil Engineering, Laboratory of Energy Efficiency in Buildings, Florianópoli, SC, 88040-900, Brazil, enedir.ghisi@ufsc.br.

Abstract: This study shows a new method used to choose design strategies for sustainable buildings. It is based on life cycle energy assessment and life cycle carbon emissions assessment. Five design strategies were evaluated in a single-family social interest house located in three cities in Brazil: Belém, Curitiba and Florianópolis. The house was evaluated based on a 63-year lifespan. The five design strategies analysed were: white painting on the exterior walls, thermal insulation of the envelope, concrete composite slab on the roof, double glass in the windows and external window shading made of hollow concrete blocks. The EnergyPlus computer programme was used to estimate the annual energy consumption only for air-conditioning with and without the design strategies. Furthermore, the impact of climate change on heating and cooling energy demand was evaluated. Results show that not all the design strategies had a positive energy and carbon emissions balance over the life cycle of the house. Also, the different climate conditions of the three cities affected the final selection of the design strategy. This research pointed out the need of using the proposed method to assure the right selection of strategies for obtaining more sustainable buildings. Choosing design strategies based solely on the operation phase of buildings should be avoided.

Keywords: Life Cycle Energy, Life-cycle Carbon Emissions Assessment, Climate change impact, Building simulation.

Introduction

The building construction sector is considered one of the largest consumers of natural resources and energy. Buildings consume 30–40% of all primary energy and natural resources over their lifespan (construction, operation, maintenance and demolition) and respond for 30% of the emission of greenhouse gases in the world (IEA, 2016; IPCC, 2011). An appropriate choice of design strategies reduces the energy demand of buildings (Griego et al., 2012). Often, the design strategy is chosen analysing only the performance of buildings during the operation phase. But, what is the best design strategy when analysing the entire life cycle of a building? A Life Cycle Assessment (LCA) is the investigation and evaluation of environmental impacts of a given product, system or service, over its entire life cycle (ISO 14040, 1997). LCA in buildings is a complex and time-consuming process. For this reason, in the last years, many researches analysed only some, or even one, of the different impact factors. Life Cycle Energy Analysis (LCEA) is used to assess the environmental impact of buildings due to energy consumption in the life cycle. Recent studies from all over the world focusing on the LCEA in buildings have been published (Paulsen and Sposto, 2013; Hong et al., 2015). These studies have shown that the embodied energy may represent up to 30% of the energy life-cycle (Thormark, 2006; Paulsen and Sposto, 2013). In addition to LCEA, Life Cycle Carbon Emissions Assessment (LCCO$_2$A) is used for evaluating the CO_2 emissions in the life cycle of a building (Atmaca and Atmaca, 2015; Costa, 2012).

Thus, the objective of this study is to propose and apply a new method for choosing design strategies for sustainable buildings.

Method

The method is divided in three main parts, i.e., (i) evaluation and modification of the climatic data; (ii) evaluation of the design strategies through the LCEA; (iii) evaluation of the design strategies using the LCCO$_2$A. In order to analyse the operational energy consumption, the EnergyPlus computer programme was used. The method was applied in a single-family house located in three cities in Brazil: Belém, Curitiba and Florianópolis. A lifespan of 63 years was taken into account as per the Brazilian standard NBR 15575-1 (ABNT, 2010).

Climatic data and tool to assess climate change

To evaluate the design strategies through the LCEA and the LCCO$_2$A the effects of climate change on the house were studied. The tool Climate Change World Weather file Generator (CCWorld Weather Gen, 2009) was used for the A2 (medium high) emissions scenario for three future time slices, the 2020s, 2050s and 2080s. The house was evaluated under the current climate data and in the three future climate data generated for each city using the weather data file in Test Reference Year (TRY) format. Recent studies explain with more details the operation of this tool (Jentsch et al., 2013; Invidiata and Ghisi, 2016).

The House

The standard design of a single-family social house funded by *Caixa Econômica Federal* (2007), the most important financing agency for the housing sector in Brazil, was used as a base case. It is a one-storey house in contact with the ground. The ceiling height is 2.60 m. It consists of one kitchen, one bathroom, two bedrooms and one living room, with a total floor plan area of 38.16 m^2 (Fig. 1).

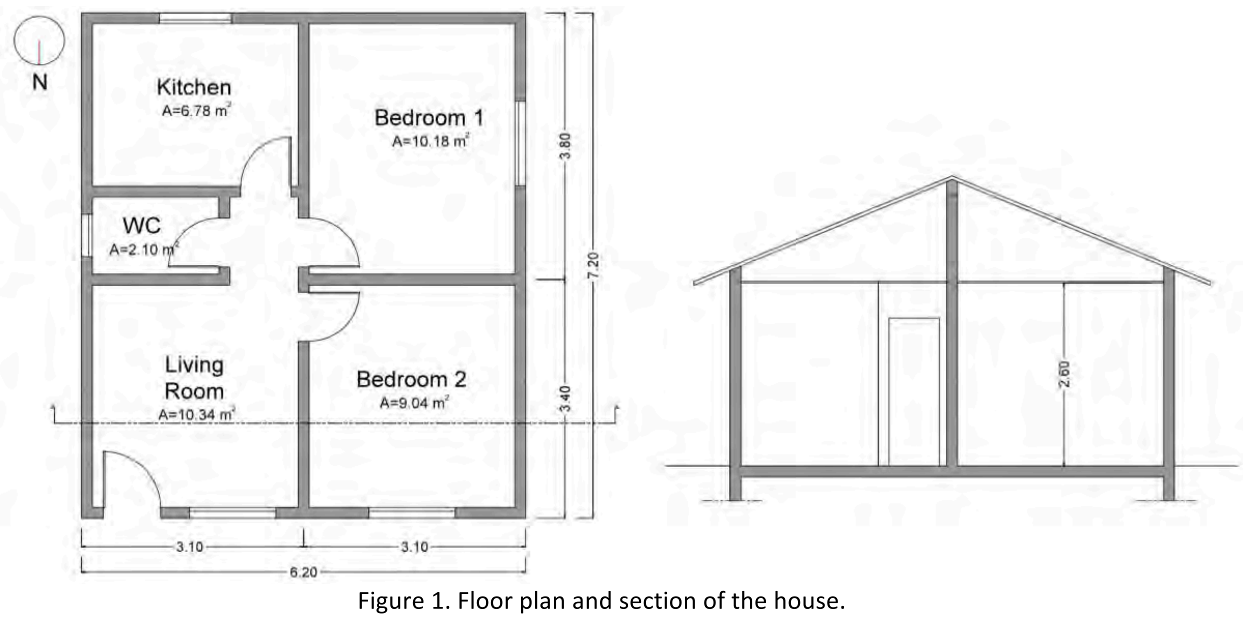


Figure 1. Floor plan and section of the house.

The internal and external walls are made of red ceramic bricks 14 cm thick and a layer of mortar 2.5 cm thick on each side. The pitched roof is made of a wooden structure with a surface of clay tiles. The ceiling is a free-hanging structure made of PVC sheets. The floor is made of a concrete layer 5 cm thick covered with ceramic tiles. The windows are composed of aluminium frames with two sliding panels of single glass 3 mm thick. Table 1 shows the thermal characteristics of the envelope of the house.

Table 1. Thermal characteristics for each component of the house.

Component of the house	Thermal transmittance (W/m^2k)	Thermal capacity (kJ/m^2k)	Solar absorptance (%)	Solar factor (%)
Roof	1.75	21	35	-
External wall	2.46	150	50	-
Floor	4.00	294	-	-
Glass	5.00	-	-	85

Design Strategies

The five design strategies analysed were: white painting on the exterior walls, thermal insulation of the envelope (expanded polystyrene − EPS), concrete composite slab on the roof, double glass in the windows and external window shading made of hollow concrete blocks. The last two design strategies were applied only in the windows of the two bedrooms and living room. It was taken into account that the single glass and the PVC-sheets ceiling of the base case were replaced, respectively, with double glass in the windows and concrete composite slab on the roof. The amount of material for each strategy was obtained from the manufacturer's catalogues. The embodied energy of the materials was obtained from ICE database (2011). The carbon dioxide emissions of the materials were obtained from Costa (2012). The five design strategies were simulated one at a time. Table 2 shows details on the five design strategies.

Table 2. Characteristics of the five design strategies analysed.

Design strategy	Material	Quantity (kg)	Embodied energy (MJ/kg)	Carbon coefficients ($kgCO_2/kg$)
Painting	Paint	8.1	79.71	0.700
Thermal insulation of the envelope	EPS	207.6	100.09	2.700
	Plasterboard	755.1	4.76	0.766
	Aluminium	70.9	157.10	4.441
	Paint	2.4	79.71	0.700
Concrete composite slab on the roof	Mortar	1710.0	1.18	0.159
	Ceramic	1536.0	10.13	0.187
	Concrete	7585.0	2.92	0.404
	Iron	140.0	31.25	1.845
	Paint	2.4	79.71	0.700
Double glass window	Glass	109.0	20.10	0.844
	Aluminium	72.0	157.10	4.441
Hollow concrete blocks	Concrete	329.0	2.92	0.184
	Mortar	39.0	1.18	0.159
PVC-sheets ceiling	PVC	77.2	70.61	0.615
Single glass window	Glass	27.0	20.10	0.844
	Aluminium	32.0	157.10	4.441

Computer simulation

In order to assess the energy demand of the house in the different cities and future climates the EnergyPlus computer programme, version 8.4, was used. The house was evaluated considering the constant use and occupation for a family composed of four persons, for the three climate data files. Details on occupation, thermal load and use pattern were taken based on the Brazilian regulation for energy efficiency in buildings (BRASIL, 2012). Equipment and lighting operated with 100% load during the operational hours. Through computer simulation it is possible to obtain the energy demand for heating and cooling the house. The house was evaluated considering only the use of an air-conditioning system; its use was defined according to the indoor occupation of the house (bedrooms and living room).

Life Cycle Energy Analysis (LCEA)

In this method, only the design strategies are analysed through the LCEA. Other materials that make up the building are not evaluated. Through this analysis, it was possible to identify the energy balance, i.e., the energy saved over the house life cycle through the use of the design strategies (Eq. (1)).

$$LCEb = OEs - (EE+ME+DE) + ELS \tag{1}$$

where LCEb is the energy balance (kWh); OEs is the operational energy saved due to the use of the design strategy (kWh); EE is the embodied energy in the design strategy (kWh); ME is the maintenance energy due to the design strategy (kWh); DE is the demolition energy in the design strategy (kWh); ELS is the energy life-cycle of the component in the base case that will be replaced by a design strategy (e.g. single glass and the PVC-sheets ceiling).

The embodied energy of the design strategies was obtained from ICE database (2011) (Table 2). For transportation of the design strategy from the manufacturer to the retailer, the distance of 250 km was adopted in the different LCEA phases. For transportation of the workers to the construction site, the distance of 50 km was adopted in the different LCEA phases. Table 3 shows the lifespan of design strategies and the other maintenance work based on the Brazilian standard NBR 15575-1 (ABNT, 2010). For transportation of the design strategy from the building to the closest landfill site, the distance of 50 km was adopted in the three cities.

Table 3. Lifespan of design strategies.

Design strategy	Lifespan (years)	No. of replacements	Maintenance
Painting	10	5	Annual cleaning
Thermal insulation of the envelope	35	1	-
Concrete composite slab on the roof	63	0	-
PVC-sheets ceiling	20	2	-
Double glass window	20	2	Annual cleaning
Single glass window	20	2	Annual cleaning
Hollow concrete blocks	30	1	Annual cleaning

Life Cycle Carbon Emissions Analysis ($LCCO_2A$)

After analysing the design strategies using the LCEA, they were evaluated through the life cycle carbon emissions assessment. Also in the $LCCO_2A$ only the design strategies were analysed. The carbon emissions balance is the CO_2 saved over the house life cycle through the use of the design strategies (Eq. (2)).

$$LCO_2b = OCO_2s - (ECO_2 + MCO_2 + DCO_2) + ECO_2 \quad (2)$$

where LCO_2b is the carbon emissions balance ($kgCO_2$); OCO_2s is the operational carbon emissions saved due to the use of the design strategy ($kgCO_2$); ECO_2 is the embodied carbon emissions in the design strategy ($kgCO_2$); MCO_2 is the maintenance energy due to the design strategy ($kgCO_2$); DCO_2 is the demolition carbon emissions in the design strategy ($kgCO_2$); ECO_2 is the life cycle carbon emissions of the component in the base case that will be replaced by a design strategy (e.g. single glass and the PVC-sheets ceiling).

The carbon dioxide emissions of the design strategies were obtained from Costa (2012), as shown in Table 2. In the operational phase, the average generation factor used to convert electricity consumption into carbon emissions is 0,137 $kgCO_2/kWh$ (BEN, 2015).

Results

Life Cycle Energy Analysis (LCEA)

First, the design strategies of the house were evaluated using the LCEA in the three cities. Fig. 2 shows the energy balance of the house with the five design strategies in the three cities. All strategies obtained a better energy balance in the hot climate (Belém). This is due to the increase in energy demand for future climate change. The results show that the concrete composite slab on the roof obtained a negative energy balance in the three cities, like the thermal insulation of the envelope in Curitiba. The painting on external walls and the double glass windows resulted in the greatest reduction of energy consumption in Florianópolis. In Belém the best design strategy was the thermal insulation of the envelope. The shading device made of hollow concrete blocks obtained a positive energy balance in all cities.

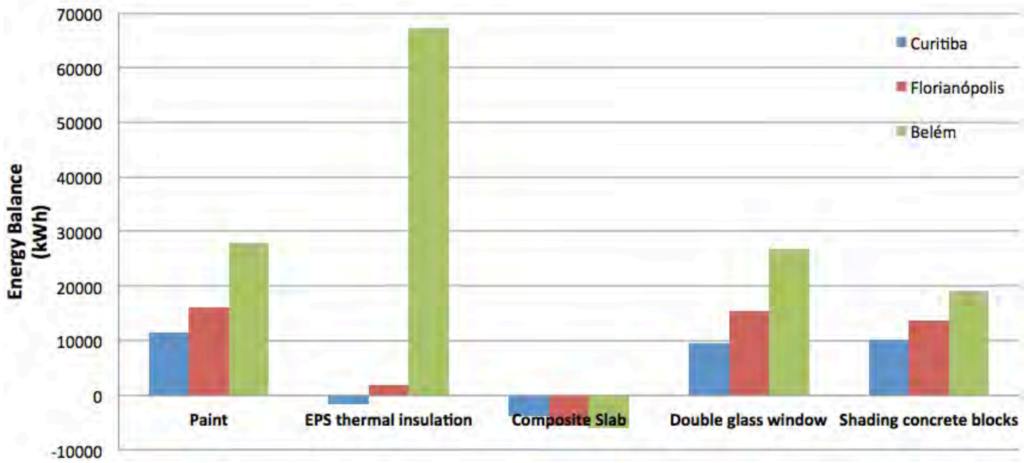


Figure 2. Energy balance for the design strategies in the three cities.

Life Cycle Carbon Emissions Analysis (LCCO_2A)

Following the evaluation of the design strategies using the LCEA, the design strategies were analysed considering their life cycle carbon emissions. Fig. 3 shows the carbon emissions balance for the five design strategies in the three cities. The results show that the concrete composite slab on the roof obtained a negative CO_2 balance in the three cities, like the thermal insulation of the envelope in Curitiba and Florianópolis. The painting on external walls obtained the greatest reduction of carbon emissions in Curitiba and Florianópolis. In Belém the best design strategy was the thermal insulation of the envelope, with carbon emissions savings over 2000 kgCO_2. Painting, double glass and shading on windows made it possible to reduce the carbon emissions in the three cities.

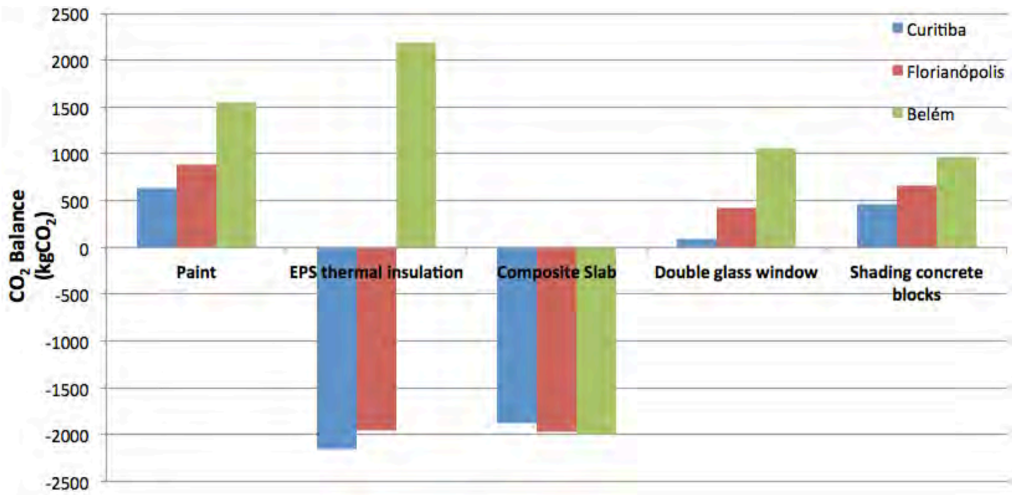
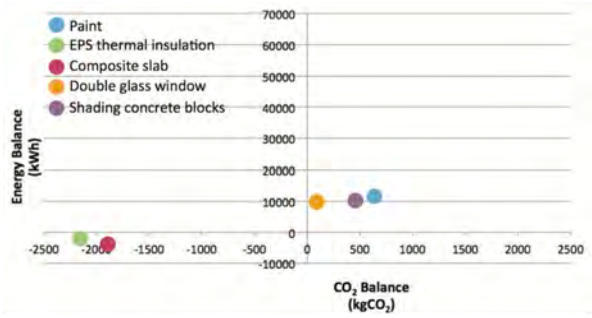


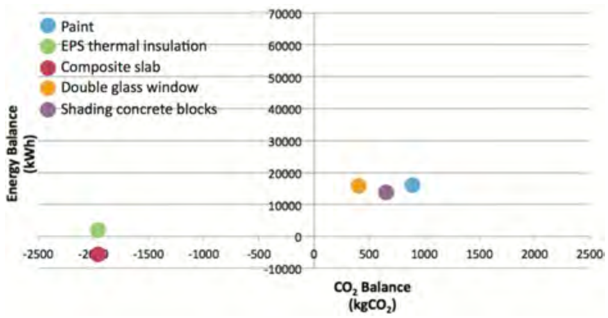
Figure 3. Carbon emissions balance for the design strategies in the three cities.

Summary

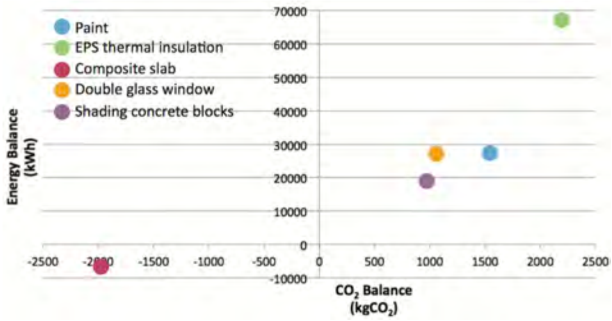
Once the design strategies were evaluated through LCEA and LCCO_2A, the relationship between the energy cycle and the carbon cycle was analysed. Fig. 4 shows the results of the energy balance and the carbon emissions balance for the five design strategies evaluated in the three cities. Each point in the graph represents a single strategy. The point at the top right position in the graph represents the best solution. The best design strategy in Curitiba was the painting on external walls, reducing the energy demand and the carbon emissions of the house. The shading and the double glass in the windows obtained positive balances, while the concrete composite slab on the roof and the thermal insulation of the envelope obtained a negative energy and carbon emissions balance. In Florianópolis the design strategies led to results similar to those of Curitiba, except for the thermal insulation of the envelope that resulted in a positive energy balance but a negative CO_2 balance. Finally, in Belém only the concrete composite slab on the roof obtained a negative result in both balances, while the other design strategies allow to decrease both energy and carbon emissions in the life cycle. The thermal insulation of the envelope was the best design strategy for Belém.



(a) Curitiba



(b) Florianópolis



(c) Belém

Figure 4. Relationship between LCEA and LCCO$_2$A for the different design strategies.

Conclusions

This paper has presented a detailed case study of a life cycle energy and carbon emissions assessment for different design strategies in three cities in Brazil. The importance of evaluating design strategies in buildings not only in the operational phase but also during the entire life cycle was observed. This is evident, for instance, if one compares the replacement of the PVC sheets in the ceiling with a concrete composite slab. The concrete composite slab reduced the energy demand during the operational phase but resulted in worse energy and carbon emissions behaviour over the life cycle of the house. Also, in the three cities, the behaviour of design strategies was different due to the several climate conditions. This method has some limitations; for instance, in the demolition phase the re-use of the design strategies was not considered. Nevertheless, through the combined analyses of LCEA and LCCO$_2$A, it was possible to identify the best design strategies to reduce the energy consumption and the carbon emissions of a house during its lifespan. The method shown herein may become a useful tool for designers to choose the design strategies with the lowest environmental impact.

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Identification of the best positions of the main facades of a solar-friendly building shape as a forward problem in the building design

Stoyanka Ivanova[1]

[1] Department of Computer-Aided Engineering, University of Architecture, Civil Engineering and Geodesy, Sofia, Bulgaria, email solaria@mail.bg

Abstract: Generation of a building shape is a creative process, where some tasks are processed as forward problems and others – as inverse problems. The science defines a forward problem as a process of calculating that starts with causes and then produces the results. Contrariwise the inverse problem starts with a result and then checks its interaction with the causes. In a complex urban environment with many neighbouring shading objects, the generation of a building shape is usually decided as an inverse problem. The architect creates a new building shape and studies its interaction with the incident solar radiation. In the best case, the architect could try several building shapes and choose that with best results. This still does not mean that it could not exist another untested shape with better solar performance. The approach proposed in this paper helps the architect to find the best positions of the main facades of the designed building in a complex urban environment. This contributes to use better the solar potential of the plot.

Keywords: solar building design, building shading factor, rose of radiation

Introduction

Generation of a building shape is a creative process, where some tasks are processed as forward problems and others – as inverse problems. The science defines a forward problem as a process of calculating that starts with causes and then produces the results. Contrariwise the solution of an inverse problem starts with a result and then checks its interaction with the causes.

While an architect determines the building shape at the beginning of the design process, the following factors influence the decision:

- Approach to the building and positioning in the urban environment;
- Functions of the building;
- Compositions' considerations;
- Engineering considerations (supporting structure);
- Compactness.

For passive low-energy buildings, it is appropriate to add the efficient utilization of solar energy to the above considerations. Solar resources are critical for the passive heating, the natural lightening and the active solar systems, integrated into the building envelope.

In the architectural design, the architect usually creates a building layout and corresponding building shape and then checks how this building shape corresponds to the requirements of the building. In the solar architecture where the solar passive design is important, the designer tests the interaction of the created building shape with the available solar resources and this is an approach as to an inverse problem. In the best case, the architect could try several building forms and choose that with best results. This still does not mean that it could not exist another untested shape with even better solar performance.

Different software products that might be used to estimate the seasonal solar irradiation on building surfaces in the complex conditions of an urban environment, where many shading buildings and other objects exist, are available. However, such generated amount of numerical data is not comfortable for making decisions about the shape of a future building and assessing the suitability of one form or another.

There is a need to develop a methodology that can help to reduce the received massive amounts of calculated data to a summary assessment of a particular building shape.

An alternative approach is to develop a methodology that helps to identify the suitable positions of the building surfaces for the best use of the solar energy. This is already another kind of solution of a forward problem.

In a **simple environment** without shadings, the problem with building shape is easier to solve, following the simple rule that the larger façade should be with southern exposure, and shorter facades – with eastern/western exposure.

In a **complex urban environment** with many neighbouring shading objects, this task is difficult to solve. The articles by Robinson (2006), Compagnon (2004) and Ivanova (2015) recommend the use of the Rose of the solar irradiation as an indicator of the available solar resources on vertical surfaces. This graph, like the rose of the winds, is a vector diagram that illustrates the amount of the incident solar irradiation on vertical surfaces with different exposure for various periods of time (months, seasons, year) – figure 1a.

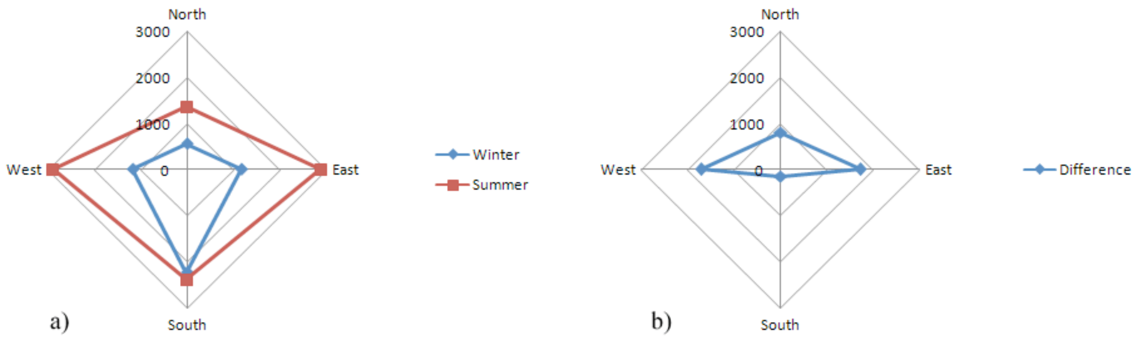

Figure 1. a) Roses of average winter (in blue) and summer (in red) daily irradiation under a non-obstructed sky in Sofia [Wh/m^2/Day]; b) Rose of the difference between summer and winter daily irradiation [Wh/m^2/Day].

Methodology

The aim of the proposed in this article approach is to support the architect to find the best exposure of the main facades of the designed building or group of buildings in a complex urban environment. This is essential for a better use of the better solar potential of the plot, as steps to create a building shape as a solution of a forward problem. For this purpose, a grid of roses of cumulative incident solar radiation and building shading factor are used.

The identification of the proper location of the designed building on the plot is one of the first design steps of the architect. Using the irradiation's roses, it is possible to evaluate the available solar resources in the nodes of a uniform orthogonal grid, placed in the plot (Ivanova, 2015), where the designed building will be situated. Such information could be guiding for the architects and urban architects in taking decision for the best position and exposure of the main facades of the designed building or group of buildings.

A simple example of a rectangular plot among tall neighbouring buildings is considered. An orthogonal grid with 3 × 3 nodes is placed over it. A virtual tall testing parallelepiped with very small square cross section is located at each node (see figure 2). Its vertical virtual walls are oriented towards the main cardinal directions (north, east, south, west). The average daily seasonal global irradiation incident to each of these 4 vertical walls of 9 testing parallelepipeds is calculated.

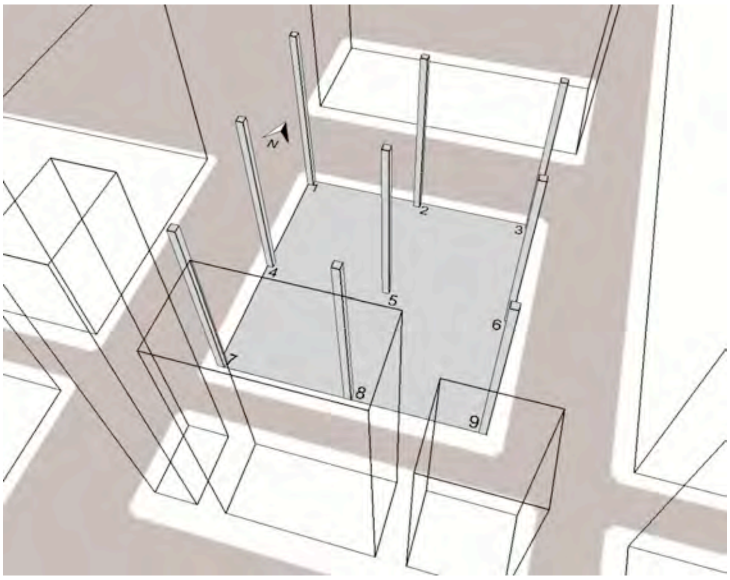

Figure 2. The composition of a considered plot and tall buildings around it.

For countries with continental climate (with cold winters and hot summers) like Bulgaria, the annual rose of solar global radiation masks and hides the different importance of solar radiation in summer and winter season. Therefore it is correct to make the calculations and analysis separately for each critical season.

For this reason, two grids of nine roses of irradiation are illustrated in figure 3. They are created using the numeric results from the program 3D-SOLARIA (Ivanova, 2014). The maximum daily winter global irradiation under a non-obstructed sky is plotted in blue (figure 3a); the maximum summer irradiation is given in red (figure 3b). The green contours in figure 3 present the incident vertical daily irradiation under the real sky, partially obstructed by other buildings and objects. The distance between blue (or red) contours and the green contours illustrates the amount of the blocked irradiation because of the urban shading.

In our previous article (Ivanova, 2015) it was explained that if we need large amount incident winter radiation and reduced amount of summer radiation, we get the best results for walls whose difference between summer and winter values of the incident irradiation is minimal (figure 1b). This means that the solar radiation incident on them is relatively permanent in the seasons. The opposite option (maximum difference between summer and winter radiation) means that there is a shortage of radiation in winter (this case needs more energy for heating), and excess of heat in the summer (it leads to additional costs for cooling).

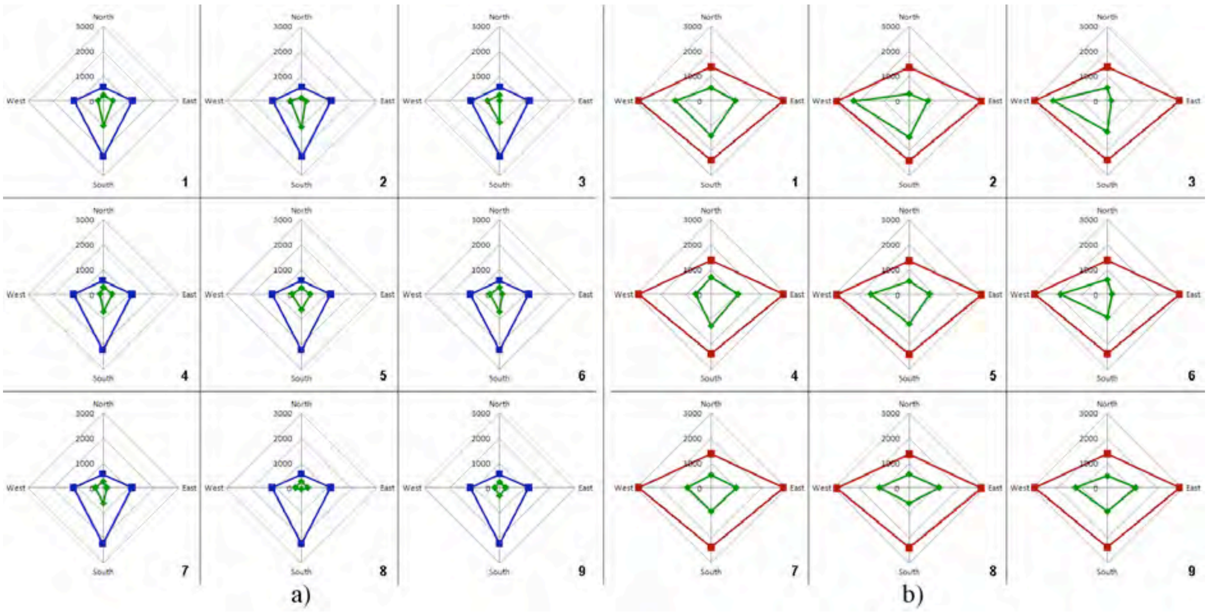

Figure 3. Roses of average daily global solar irradiation in considered 9 nodes.
The plot is located in Sofia: a) winter; b) summer.

In this article, we offer two different options to illustrate the estimated differences – with roses of solar irradiation difference (figure 4) and with 3D area charts (figure 5).

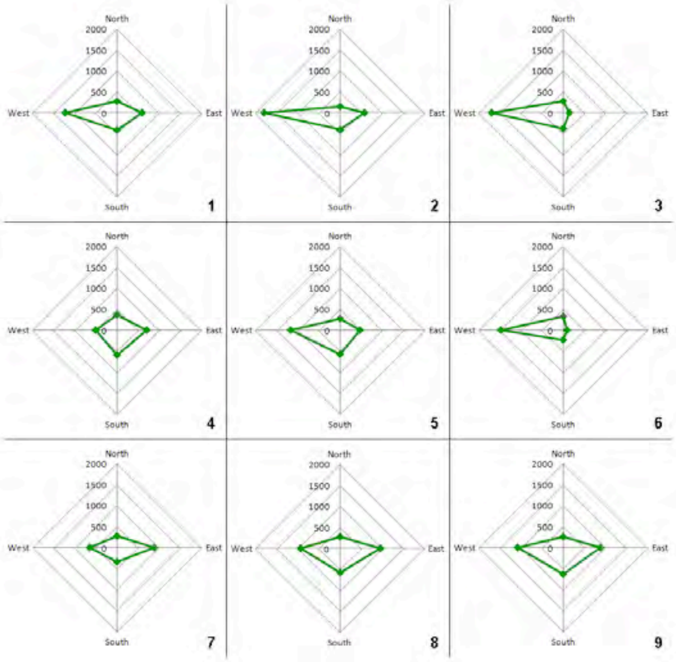

Figure 4. Roses of the differences between average daily winter and summer solar irradiation for nine considered testing parallelepipeds.

In figure 5 the left column of images displays the summer (with the lighter colour) and winter (with the darker colour) average daily irradiation on the vertical surfaces of the tested 9 virtual parallelepipeds, and the right column – the difference between summer and winter average daily irradiation. The first row of images illustrates irradiation on northern surfaces, the second row concerns the southern surfaces, the third row – eastern surfaces and last row – western surfaces.

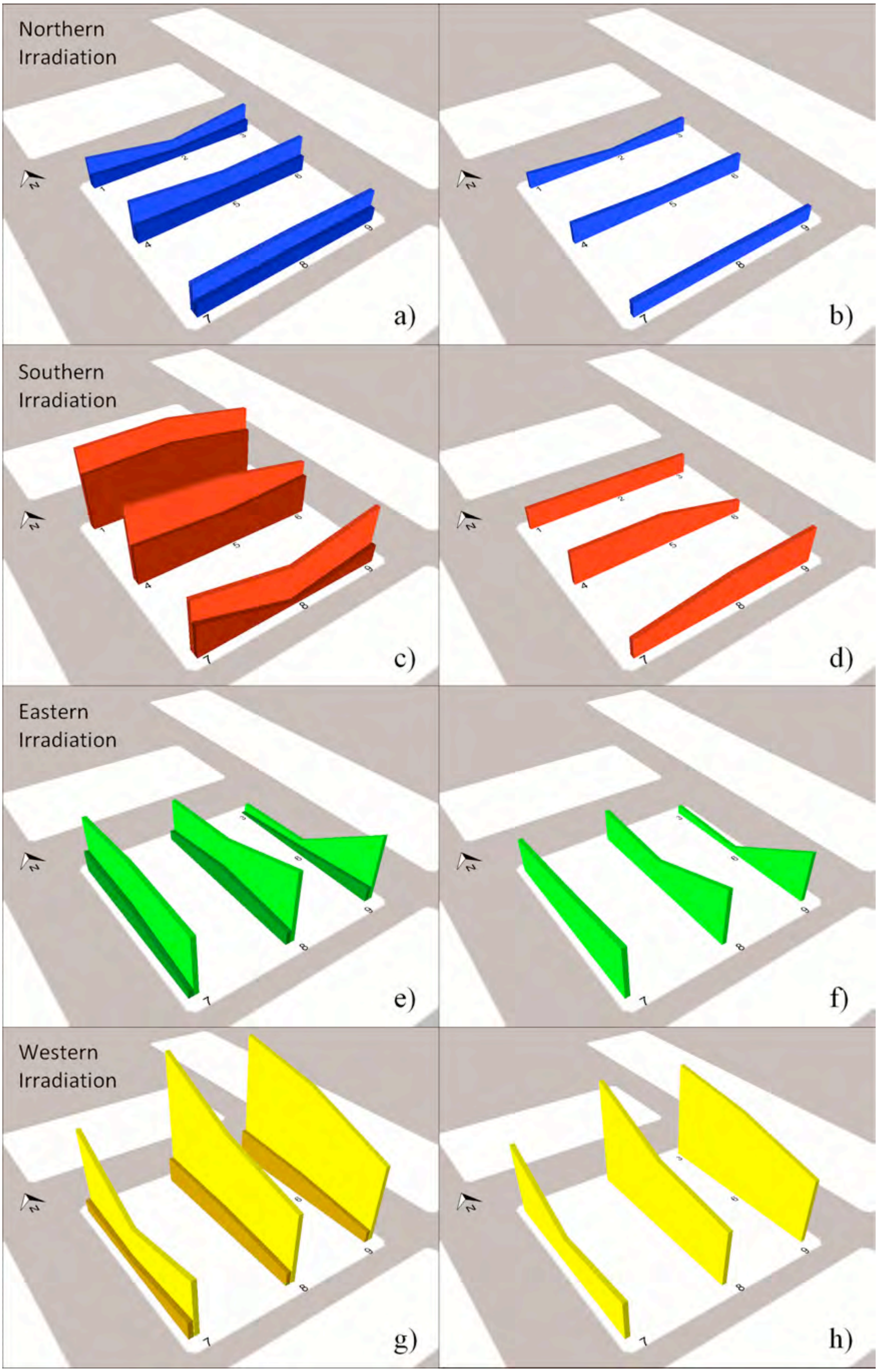

Figure 5. 3D Area charts of visualized average daily global solar irradiation on vertical surfaces:
a, c, e, g) summer and winter irradiation; b, d, f, h) difference between summer and winter irradiation.

The desirable positions for building facades on the plot are the locations with minimal differences (figure 6a, b). Such position for easterly exposure exists in the north-eastern part of the plot. A minimum difference for westerly exposure exists in the southwest part, and for southerly exposure – in the central or the northern part of the plot. The difference for the northerly exposure is nearly constant everywhere.

Based on these guidelines, we can suggest a building form composed of 3 units as it is shown in figure 6c. The largest unit has southerly exposure and is sufficiently distant from the buildings to the south of the plot. Thus it is capable of getting more direct solar radiation. The western unit is lower because of the unfavourable difference for the eastern wall in the southwest corner of the plot. The same consideration is valid for the height of the eastern unit.

Another suitable shape of the building might be the form of the Cyrillic letter "Г" (figure 6d) situated in the western and northern part of the plot, but it will be too close to the building north of the plot and would cause too large shadows on it in winter.

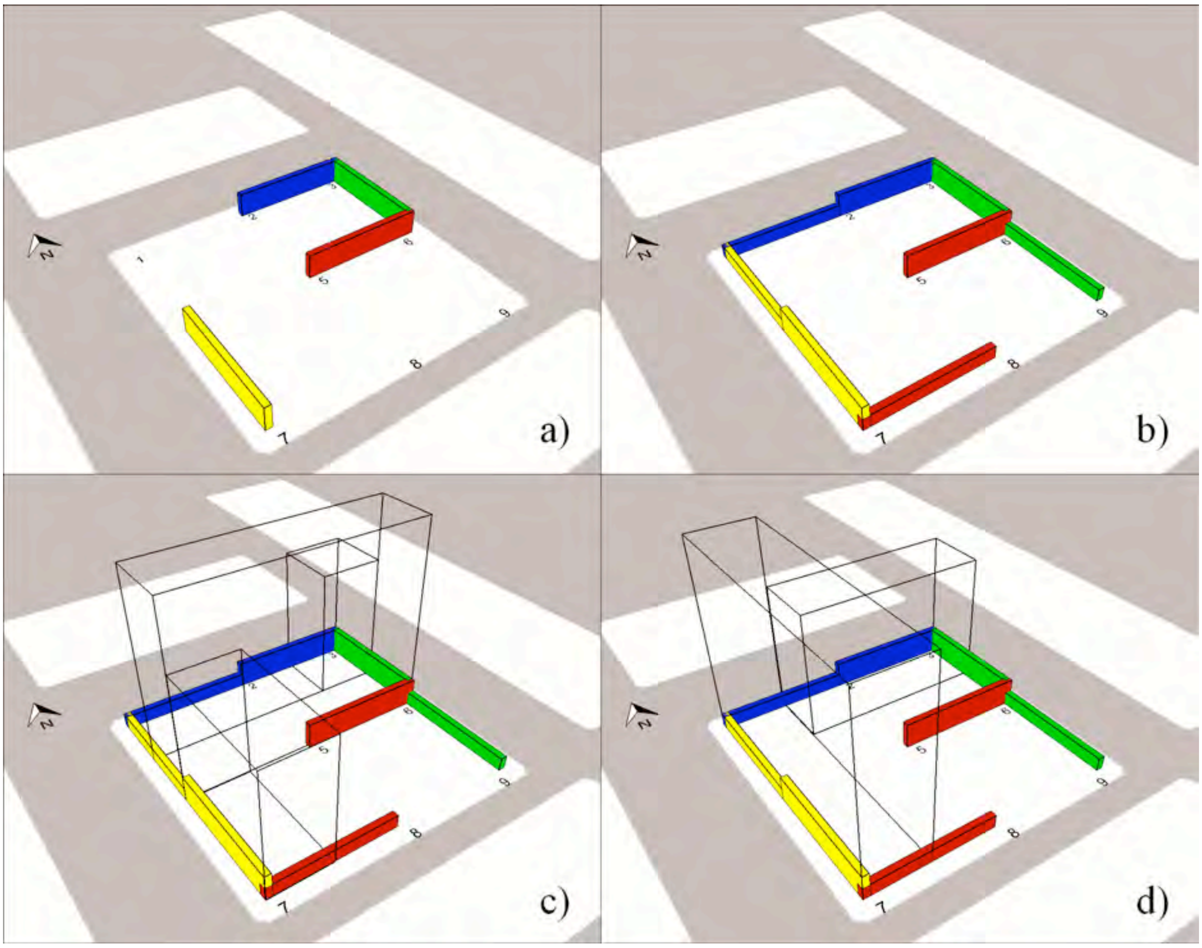

Figure 6. a) positions with smallest differences between summer and winter irradiation; b) positions with the two smallest differences between summer and winter irradiation; c, d) two proposed building shapes according to this analysis.

The proposed shapes reflect both the normal expectations for shading in the environment with tall buildings and the irregularity in the shading due to the uneven locations of neighboring buildings and their various heights. The two proposed building shapes have to be checked in the next stage with a detailed calculation of their building shading factor.

Evaluation of building shape with Building Shading Factor

The interaction between the available solar energy, the shape of the future building and the obstructing objects in the surrounding urban environment can be evaluated quantitatively with the help of a **Building Shading Factor** (*BSF*). It represents the ratio of the blocked solar energy that fails to reach the explored building surfaces and the maximum possible incident solar energy on these building surfaces under the non-obstructed sky (Ivanova, 2014). Architects can use the calculated numeric value to assess the shading effect caused by surrounding urban environment and the self-shading effect caused by building elements participating in the composition of the studied building. The methodology is implemented in the computer program 3D-SOLARIA.

The building shading factor has a different meaning in winter and summer. The higher values in winter are due to low sun. Therefore, lower value of the factor indicates better building shape. *BSF* in summer has lower values than in winter due to high sun. Logically, higher *BSF* values correspond to better building shapes that offer better shading. There are buildings and complexes with seasonal use (for instance summer and winter resorts), and buildings that are used all year round. In these buildings the sought compromise between winter and summer shading factors is different. For buildings for summer living the architect seeks a maximum value of BSF, while for buildings for winter habitation a minimum *BSF* is targeted. In buildings for permanent habitation, the best solution is characterized by minimal difference between winter and summer values of *BSF*.

As an example, three buildings variants (figure 7), placed in the same considered plot, are evaluated. Their volume is equivalent V=18000 m^3; the external surface is A=4900 m^2. The calculated values of their form factors are equivalent also: $FF=A/V$= 4900/18000=0.2722.

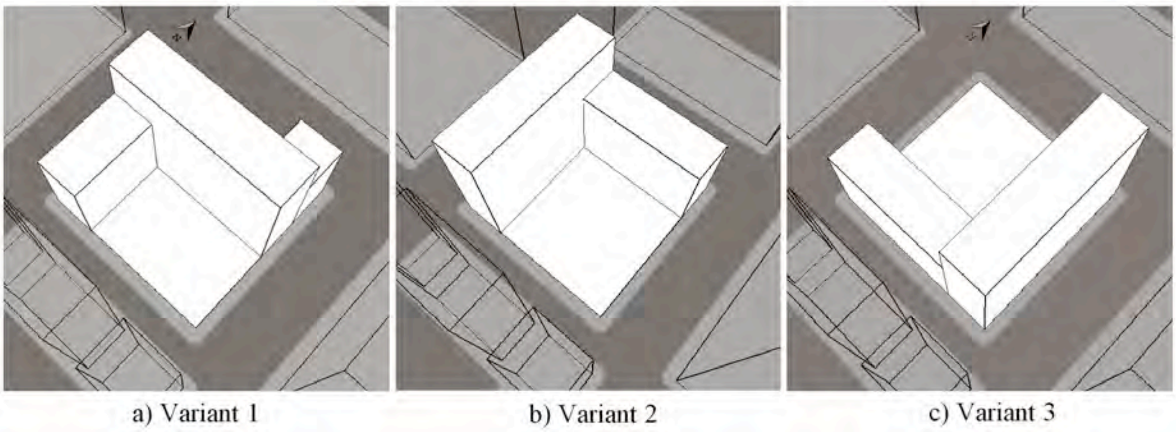

Figure 7. Three variants of building shapes with equivalent values of volumes, external areas and form factors

The first variant (figure 7a) is proposed after the performed analysis (see figure 6c). The second variant (figure 7b) was the other configuration recommended due to the same analysis. The third variant (figure 7c) has a shape, equivalent to the second shape, but rotated at 180°.

After the estimation of the incident solar global radiation on the building surfaces the following results were calculated and illustrated in figure 8:

- Variant 1 – BSF_{winter} = 0.715; BSF_{summer} = 0.553; difference 0.162;
- Variant 2 – BSF_{winter} = 0.712; BSF_{summer} = 0.546; difference 0.166;
- Variant 3 – BSF_{winter} = 0.743; BSF_{summer} = 0.534; difference 0.209.

According to these results, the first of the considered three building variants is the best one because it has a minimum difference between the winter and summer values of *BSF* (0.162). The second variant is estimated as very close to the first one (difference 0.166). The third variant, even if it has the same shape as the second but rotated, is the worst (difference 0.209).

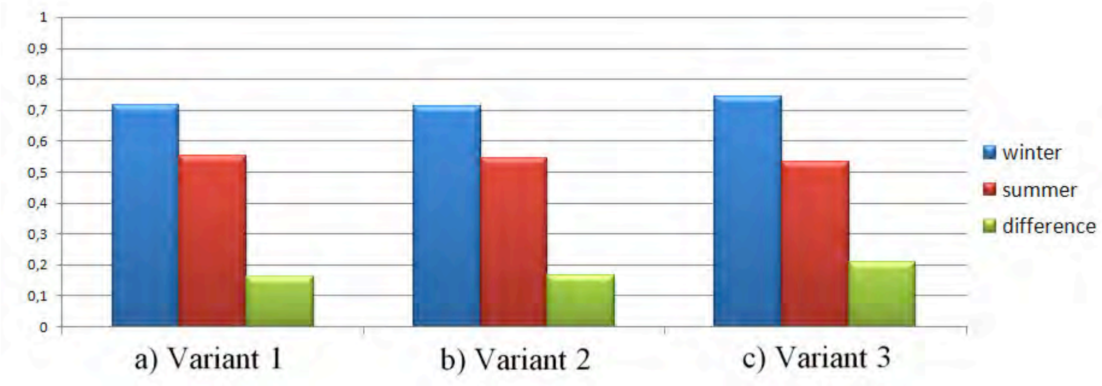

Figure 8. Values of BSF for winter (in blue), summer (in red) and the difference between them (in green) for the considered three variants of building form.

The first building variant will receive the most relevant seasonal amount of solar energy on its surfaces in comparison with two other considered variants, as it was assumed after the analysis of the estimated difference between summer and winter irradiation.

Conclusions

The solar resources are very important in the passive low-energy architecture. In this article, we recommend a new approach to identify the positions on the building plot which are most suitable for the building facades. This information could help the architect to create solar-friendly building shapes as a solution of a forward problem. The proposed approach uses a grid of roses of vertical solar global irradiation, which nodes are regularly placed on the plot. The increasing of the number of the grid nodes will be suitable for buildings with a more sophisticated shape. Then the proposed variants of building shapes have to be ranked with a calculation of their building shading factors. The variant with most relevant energy resources is the one with the largest difference between winter and summer values of *BSF*.

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Design to Thrive

Improving Thermal Performance of Traditional Cabins in the High-Altitude Peruvian Andean Region

Cecilia Jimenez, Martin Wieser and Susana Biondi

Pontificia Universidad Católica del Perú PUCP, Lima, Perú

Abstract: Communities in the high-altitude region of the Peruvian Southern Andean Mountains are located over 4200 meters above sea level. Communities organize in isolated cabins dispersed in an extensive area surrounding the community center. The harsh natural environment and poor living conditions affect people's health and increase child mortality, especially in winter. Daytime solar radiation is of high intensity. At night exterior temperatures are -10^{o}C, while indoor temperatures of cabins barely reach 0^{o}C. This research sought to improve the thermal performance of these cabins with passive design strategies and local resources. The methodology included: a) collection of weather data versus indoor thermal performance, availability of local resources and understanding domestic organization patterns; b) definition of comfort temperature range and analysis of local materials; c) technology transfer by involving the population in the construction of a prototype. Simple passive strategies of air tightness and solar gain with local available materials (adobe for walls, totora reed (Schoenoplectus tatora) and sheep wool for insulation, and stone and wood to waterproof the floor) improved night thermal performance in these isolated areas. Although local people are starting to implement these techniques in their own cabins, this is just the starting point towards appropriate thermal comfort.

Keywords: Thermal Performance, Passive Solar Design, Totora Insulation, Vernacular Architecture, Tropical high altitude climate

Introduction

The high-altitude Southern region of the Peruvian Andean Mountains is located in between 4000 and 5000 meters above sea level. The main economic activity of communities in this region is alpaca breeding, which organizes the community in isolated cabins dispersed in an extensive area surrounding the community center and market. Agriculture is not feasible; only "ichu" grass (Stipa ichu) grows everywhere, which is the main food for alpacas. People live in extreme poverty and poor living conditions, with neither electricity nor water system. These circumstances affect people's health and increase child mortality, especially in winter, when "heladas", nighttime frost, are frequent; young alpacas' mortality also increases during this season thus affecting their main income.

The typical cabin in this region has three separate modules: bedrooms, kitchen and storage room, made of stone walls and occasionally with adobe bricks, earth floor, small or no window holes, metal doors and roof, and no insulation. Originally the roof was thatched with the local "ichu" straw, but currently it has been replaced by tin metal roof sheets over thin wood rafters, given that it is more economic, it is more "modern", and nowadays it is not feasible to get "ichu" straw with the required length. This change worsened the thermal performance of cabins. Field measurements during the coldest months showed indoor temperatures around 0^{o}C at night.

Figure 1. Quella-Quella, a typical cabin and landscape of the high altitude region

According to weather data collected for three months in one of these communities, Orduña, average air temperature during the day is 12.5°C and -4.1°C at night. There is not a significant seasonal variation and the diurnal thermal range is moderate to high (around 16°C). However, due to climate change, climatic conditions are unstable, unpredictable and there are more frequent frost events at night. Relative humidity has significant variation during the day and day after day. However, on average, relative humidity is low at midday, in between 10% and 40%.

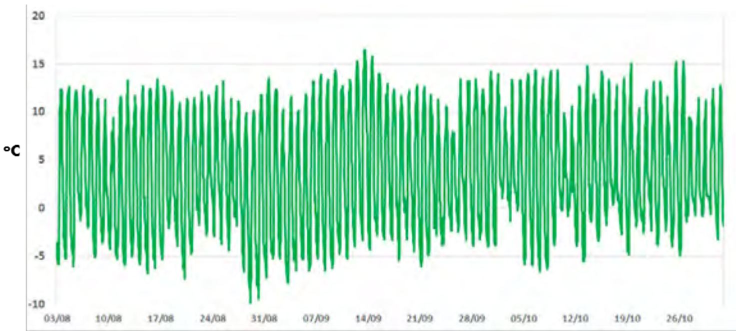

Figure 2. Outdoor Temperature in °C

Solar radiation is constant and very high throughout the year. The average daily total of the three months of measurements is 6kW/m^2. However, maximum daily total can reach 8kW/m^2, and minimum daily total is around 3.5kW/m^2. It is important to note that 75% of the time solar radiation was over 5kW/m^2, while only 5% of the time solar radiation was below 4kW/m^2. Winds are constant, with moderate speed and coming from diverse directions. Maximum speed is in the range of 3 and 5 m/s at noon, and decreases significantly at night, becoming completely calm at dawn, when it is also the moment of the day with the lowest air temperature.

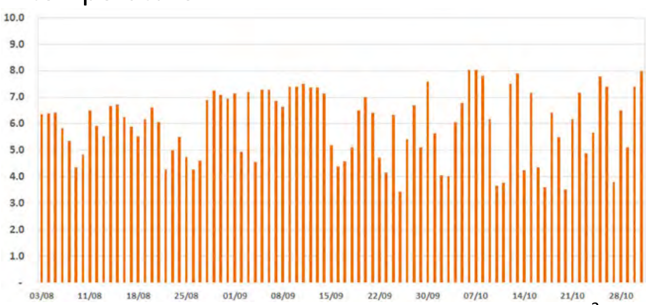

Figure 3. Global Horizontal Solar Radiation (kW/m^2)

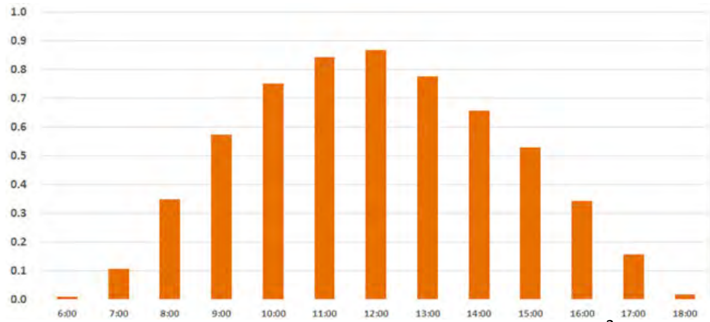

Figure 4. Daily Average Solar Radiation (kW/m^2)

Given these conditions, this is a proposal to improve the thermal performance of the dwellings in these isolated communities, by means of bioclimatic design strategies, local resources available in the region and active participation of the local people.

Methodology

The research focuses on Orduña and is a section of a multidisciplinary project on technological transfer in high-altitude communities (Rodriguez Larrain et al, 2016). Orduña is a characteristic community of this region, at 4800 meters above sea level. It has the typical climate of the high altitude region: cool during the day and very cold at night. In addition to collecting weather data, there was a previous study on the habitat, the typical dwellings and the living practices and patterns of its inhabitants.

A portable weather station, Davis Vantage PRO2 Plus, was used to register exterior information, and data loggers ONSET Hobo H08-003-02 and Extech registered air temperature and relative humidity within the cabins. Actual air temperature data was collected in different months from 2014 to 2016, with a total of 150 days of measurements. Only 7 of the 150 days air temperature at night was above 0^{o}C, giving an average minimum temperature of -5^{o}C. It may be concluded that frost occurs throughout the year, and is not related to a particular season, but rather is a constant condition in Orduña.

There are no specific studies on thermal comfort in high altitude tropical climates. Therefore, the adaptive comfort method of Nicol and Humphreys (2002) was taken as reference to calculate and define a thermal comfort range for Orduña, based on the monthly average outdoor air temperature. From the air temperature data collected, the calculated lower limit of the comfort zone is around 12^{o}C, which is much higher than the indoor temperature registered in the cabins, generally in between -2^{o}C and 2^{o}C.

Representative cabins were measured and occupation patterns and users' needs were defined in group sessions with local people.

The proposed bioclimatic design strategies focuses on increasing heat generation/gain and reducing heat losses with local resources and materials, especially the "totora" reed mattress as insulating material. The "totora" is abundant in the high Andean lakes, and for a 5cm thick mattress the average R-value is 0.74m^{2}K/W (Ninaquispe Romero et al, 2012). The strategies were evaluated with Design Builder software to select those which best improve thermal performance and are economically accessible to local people. Conductivity of selected local materials was evaluated at the laboratory to select the thermally best combination.

Basic concepts on climate and thermal performance of buildings were deployed to local people in group sessions. They were also trained in the selected bioclimatic design strategies and construction techniques by applying them in remodeling some sections of their own cabins.

A prototype cabin applying the bioclimatic design strategies was built by the local people in the communal center town with the supervision of the project team members. Once completed, the weather station and data loggers were installed to register new measurements. ONSET Hobo data loggers were placed in the three rooms of the bedroom unit (two sleeping rooms and one distribution room in the middle) to register air temperature and relative humidity. Two data loggers were placed in each room at 0.40 and 1.40 meters above floor level. Data was registered every hour from August 3 to October 31, with a total of 2160 data per item. Given that the prototype cabin was more hermetic than the standard cabin, interior air quality was also measured, specifically the CO_2 concentration with Sper Scientific 800050 equipment.

Traditional Dwelling Design and Practices

The organization pattern of the cabins has a "U" shape: the bedroom unit on the East side has two rooms with doors facing West, towards a central patio. On the North side is the kitchen unit, usually the only building with a thatched "ichu" roof; and on the South side is a storage room. The West side of the central patio has a "pirka" stone fence. One family or extended family (grandparents and/or oldest son's family) lives in a cabin.

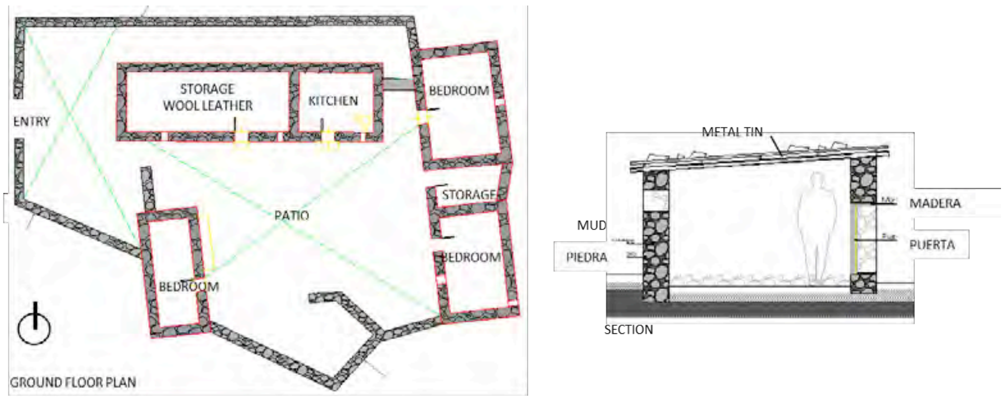

Figure 5. "Quella-Quella" Plan and section of traditional cabin in Orduña

During the day men and women are in the field pasturing the alpacas; only small children, pregnant women and elderly members of the family stay in the cabin. They usually sit in the kitchen, which is warmer, or in the sunny area of the patio. They all gather in the kitchen at about 5 to 6 in the afternoon for supper and then go to the bedroom unit. Usually two to four members of the family sleep in one room. At 5 to 6 in the morning they gather again in the kitchen for breakfast, before leaving for their daily activities.

Most of the cabins and fences are made of dry stone, which is the material readily available in the region. In the cabins, the holes among stones are covered with mud. Floors are just earth without any treatment, thus usually they are damp and increase the cold sensation within the cabin. The gaps left by the rafters in between the stone walls and the metal roof remain open. The door of each room is poorly built with cracks all around the border. The little heat generated by the people in the bedrooms, escapes from the room through the materials by conduction and through all the gaps and cracks.

Proposed Design Strategies

The bioclimatic design strategies recommended for Orduña to reduce heat loss were: materials with lower U-value, elimination of cold air infiltration through cracks and gaps, small windows to allow solar heat gain and natural light, insulated doors and window shutters. Regarding heat gain, solar radiation became the main source available, especially via skylights. These strategies are congruent with those of other authors (Olgyay, 2008) (Szokolay, 2014) (Givoni, 1998).

The base module selected to evaluate the recommended strategies was a sleeping room of 3.00 by 4.00 meters with stone walls, metal tin roof, earth floor and metal door. The longer sides of the wall face East and West. Two windows were located on the West wall, with single pane glazing and wood frame. Results from simulations with Design Builder software proved that insulation of walls and roof with 5 cm thick "totora" reed mattress was the most effective strategy to improve the thermal performance of the room (Figure 6), and to determine the following materials (Table 1):

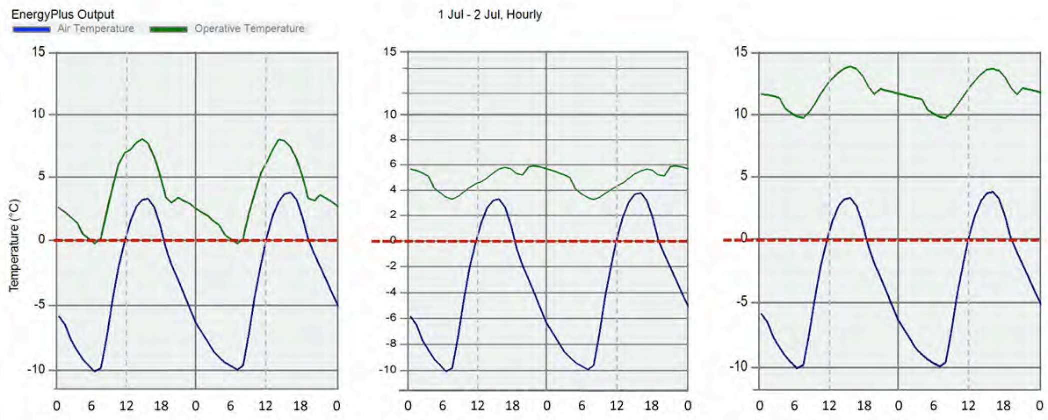

Figure 6. Results of simulations with Design Builder

Table 1. Recommended materials to improve thermal performance in Orduña cabins

Element	Materials	U-value W/m^2 ^{o}K
Roof	Metal tin sheets in the exterior for rain protection; 5 cms of a mix of mud with straw; 5 cms of insulation made of "quesanas de totora" reed mattress; wood rafters, and gypsum plaster in the interior	0.979
Walls	Adobe 40 cm thick, 5 cm of "totora" reed mattress on the exterior, and 2.5 cm of clay coating on both sides of the wall	0.581
Floor	Three layers of stone of different sizes totaling 25 cm thick, 5 cm of a mix of mud with straw, and 3 cm of hardstand earth to reduce sub-soil damp reaching the surface	1.516
Windows	Single glazing with wood frame, facing West, with 2.5 cm thick shutters made of two layers of plywood with sheep wool in between as insulation	1.370
Entry Door	Wood frame with a layer of metal sheet in the exterior, 2.5 cm thick of sheep wool insulation and a layer of plywood in the interior. It should not open directly into bedrooms but rather to an intermediate room	1.164
Skylight	Wood frame and a transparent plastic sheet. Only in the room with day-activities	5.995

Some modifications were done for the construction of the prototype cabin. The "quesana de totora" reed mattress was placed in the interior instead of the exterior of the adobe wall, due to practical purposes of maintenance and durability. Windows were open on both sides of the room, facing East and West, and the floor was completed with wood planks (Figure 7). The skylight was 0.80 x 1.00 meters and located in the distribution room Local people painted the walls white and bought furniture (beds, small tables and chairs) for the cabin bedroom unit.

Figure 7. Proposed site plan of prototype and built cabin (bedroom unit and kitchen)

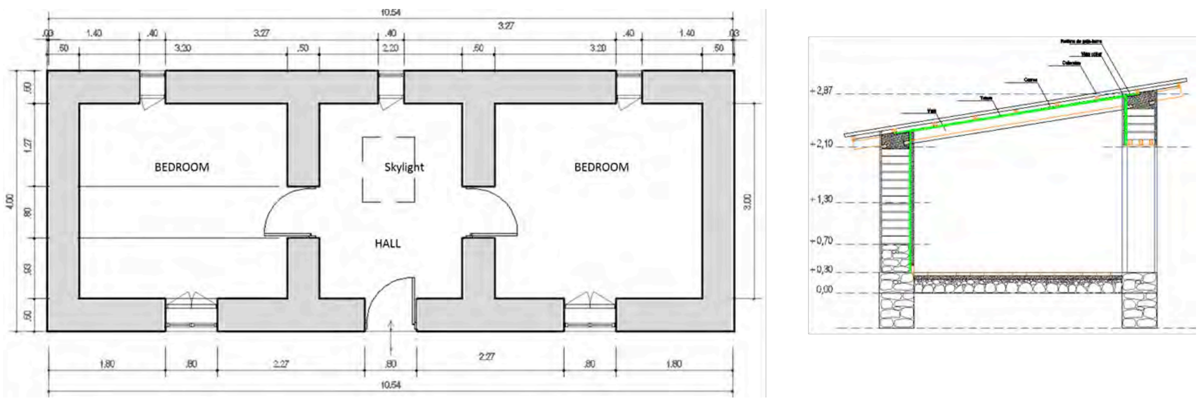

Figure 8. Floor plan and section of bedroom unit

Results

It is important to note that rooms were not consistently occupied during the three months of measurements. Results are the hourly average of the three months of registered data. In the case of the distribution room with the skylight, data was valid only for one month (August). The CO_2 concentration data was registered for 24 hours in one sleeping room with two people, who made sure the room was hermetic at night.

As indicated before, the exterior thermal range is 16°C with cold nights and cool days (Figure 9). The interior thermal range of sleeping rooms is only 4°C to 5°C, while in the distribution room with the skylight the thermal range is 12°C. During the coldest hours of the night, interior temperature of the prototype sleeping rooms are 8°C above exterior temperature and 4°C above temperature of traditional cabins, which is an improvement, but still not high enough to reach contemporary comfort standards, as previously defined.

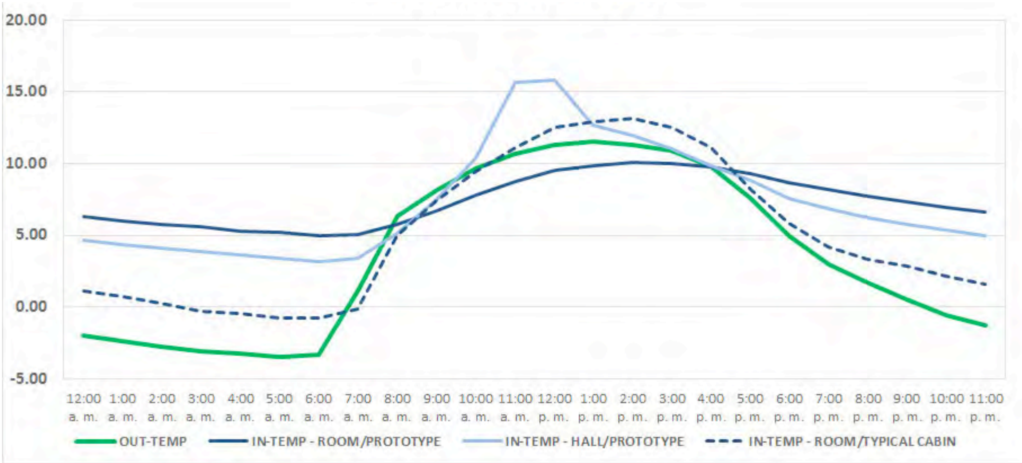

Figure 9. Air temperature in ^{o}C, of prototype bedroom unit compared to traditional cabin and outdoors

Air temperature in the distribution room is 5^{o}C higher than the sleeping rooms, but also 1^{o}C to 2^{o}C lower at night. The difference of the air temperature registered in the sleeping rooms at 40cm and 140 cm above floor level is greater when the temperature in the distribution room is the highest. This demonstrates that warm air from the distribution room enters the sleeping rooms by convection during the day. Concentration of CO_2 was slightly above 1000 ppm but still within an acceptable range.

Discussion

The results show progress towards thermal comfort in Orduña cabins, but also that it is necessary to consider further improvements and additional strategies to achieve a better thermal performance of the cabins. The "quesana de totora", reed mattress worked well as insulation on the roof and walls; however they could work better on the roof by adding a layer of clay mixed with straw to guarantee there is no infiltration through interstices among reeds.

The skylight in the hall proved useful for solar gain, which is potentially the most effective strategy to improve the thermal performance of the prototype. It could work even better if all the roof of the hall is transparent and become a hot-room to transfer heat to the sleeping rooms by convection through the open doors during the day, and to collect heat on the walls adjacent to the sleeping rooms and transfer it by conduction in the evenings. The option of adding skylights in the bedrooms would require shutters that guarantee hermetical closing at night, and also that are economical, and easy to use and maintain.

Insulation of doors and windows shutters with sheep wool worked well. The only consideration would be to make sure the frame has no gaps or grooves. The insulated floor would prevent it to becoming a source of heat loss, as long as the interior air temperature rises above the exterior mean air temperature. This is especially important at night.

The floor to ceiling height of the prototype could be lower thus reducing the volume of air in the rooms to warm up and the exterior surface exposed to cold winds. It also would allow the warm air to be closer to users due to thermal stratification of the air. The color of exterior walls should remain dark to reflect the least incoming solar radiation. This has to consider the possibilities of natural clay and the acceptance of users of the cabins.

Despite CO_2 concentration is within an acceptable range, it might be required to include a simple control system for fresh air intake, when more than two persons occupied the bedrooms.

Conclusions

The implementation of basic bioclimatic concepts of thermal comfort with local resources can improve the thermal performance of cabins in isolated areas of Andean high altitude regions of South Peru. The first objective must be to make the dwellings more hermetic and insulated to prevent heat loss by conduction and infiltration. Given that Peruvian Andean regions are within the tropics, solar radiation of high intensity is the main and most effective source of heat gain, specifically through skylights.

The “quesanas de totora”, reed mats, have proved to be a good insulation material; however it is only available in the southern part of Peru.

The recommended strategies could satisfy the thermal comfort requirements of current inhabitants, but they still do not satisfy contemporary international standards of thermal comfort. It might be necessary to consider complementing the passive strategies with active ones or even with conventional heating systems. However, current economic constraints make difficult the broad implementation of non-passive systems.

Acknowledgements

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Impact of added convex windows on heating energy need and peak load in different climatic zones

Attila Kerekes

Building Engineering, Faculty of Engineering, University of Debrecen, Hungary, kerekesa@eng.unideb.hu

Abstract: Windows have a dominant role in the energy balance of buildings. Added convex windows compound the features of additional insulation, mass wall, double skin façade and the form of bow windows. They facilitate the energy conscious retrofit of existing buildings without replacing the original windows thus lower operational energy consumption can be achieved with less embodied energy and without the garbage of demolition. Heating energy consumption can further be decreased by preheating the fresh air or recovering considerable energy of the exhaust air in the added zone. The operational energy saving obviously depends on the climate and on the orientation. Detailed dynamic simulations have been carried out for three climatic zone and different orientations. Calculated results have been checked with measurements of custom made cabins in Hungarian conditions. The investigations prove the considerable energy saving potential of added convex windows. A problem has been discovered and analysed. To achieve low energy consumption a higher built-in capacity of the heat source is required to meet the increased glazed ratio. This reveals the problems of many building regulations, which encompass the peak output of the heat source although the final goal is the low primary energy consumption and the related emission.

Keywords: glazed ratio, added window, heating energy need, peak load

Introduction

Windows in general are the weak points of the energy balance of existing buildings – obviously most energy conscious retrofits begin with changing windows, which is accompanied with serious disturbance of inhabitants and the problem of demolished material.

The “added” convex windows are put on the façade from outside whilst the original windows remain in place. The contour of the added windows is optional: polygonal, curved, asymmetric or symmetric. The form (from outside) is similar to that of the bay or bow windows: a traditional architectural feature in the UK. The area of the façade covered by the added window is greater than that of the original window: it means that all constructional joints, edges, bearers, windowsills: in one term all thermal bridges around the original windows are covered: thermal bridge losses and risk of fabric damages decrease. In the buffer zone (between the original and the added windows) the temperature increases due to the modest greenhouse effect, the covered massive wall around the original window acts as a mass wall. A further side effect is that the air tightness of the façade is improved. The ventilation air can be channelled through the buffer zone facilitating heat recovery from the transmission heat loss (in case of inlet) or from the leaving air (in case of exhaust). The schemes of different states and the model are shown in Fig. 1.

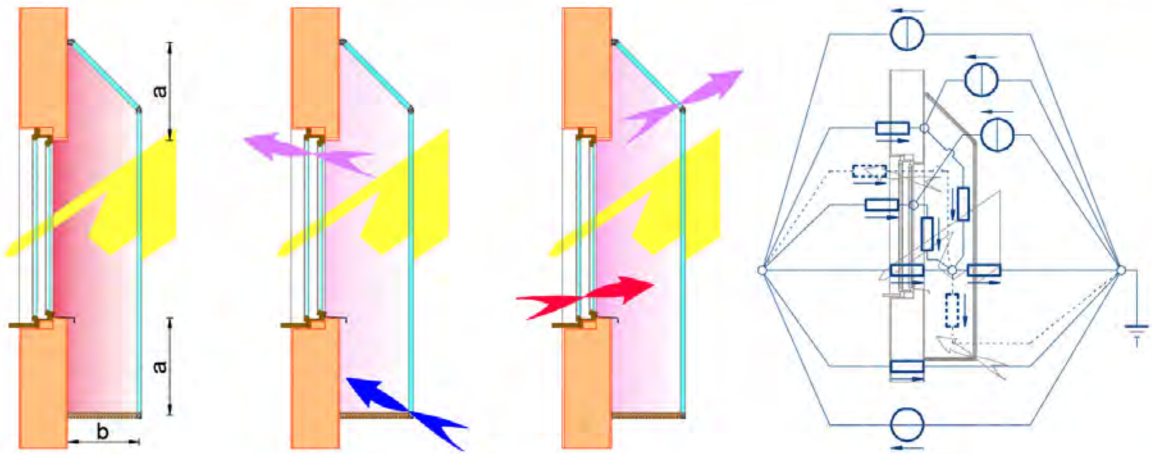

Figure 1. Scheme of added windows: buffer and greenhouse effect, fresh air preheating, exhaust air heat recovery and simplified model.

The width of the wall covered by the added window around the original window (as shown in Fig. 1, size "a") and the depth of the added window (as shown in Fig. 1 "size b") should be chosen between 20 and 40 cm for convenient installation and use. In our calculations the dimensions "a" and "b" were therefore taken into account as 40 cm.

Measurements have been taken, which show that using shades (to reduce upwarming) are the same effective in the case of using external shades on the original window, and in the case of using interior shade in the added window.

Methodology

Different combinations of walls and original windows (U and g values), glazing of added windows (single and double) have been analysed in the function of the glazed ratio (the last relates to the original windows) for three orientations. Dynamic simulation has been carried out using Energy Plus v.8.4.0 software for different climatic zones: the model is a room of five adiabatic boundaries and the varying façade. Air change rate 0.5/h and 55 W internal gain were considered. Heating energy need and net peak load of heating system have been calculated. Some of the results are shown on Figs 2-5. Three zones have been selected: the home location Debrecen {N 47° 28'} {E 21° 37'} Dfb (climate type in Köppen classification based on Kottek et al (2006)) in continental zone, a location close to Edinburgh: Leuchars {N 56° 22'} {W 2° 52'} Cfb and Bergen {N 60° 17'} {E 5° 13'} Cfb.

The following two base cases will be analysed in detail. The first one is an old façade of masonry wall and a low quality window. The effects of added windows are shown in Figs. 2. and 3. – it is important to notice that the refurbishment of the façade is restricted exclusively to the use of added windows.

Obviously a complex refurbishment includes the thermal insulation of the massive wall too. This is the second case, where the thermal insulation of the wall is improved up to the level of nearly Zero Energy Buildings, however instead of replacing the old windows they are kept and added windows are applied.

Three states have been considered. 1. Buffer and greenhouse effect, when no air flow passes the buffer zone (ventilation is provided via another intake). 2. Preheating of fresh air. 3. Heat recovery from the leaving air.

The results are shown in Figs. 2-5.

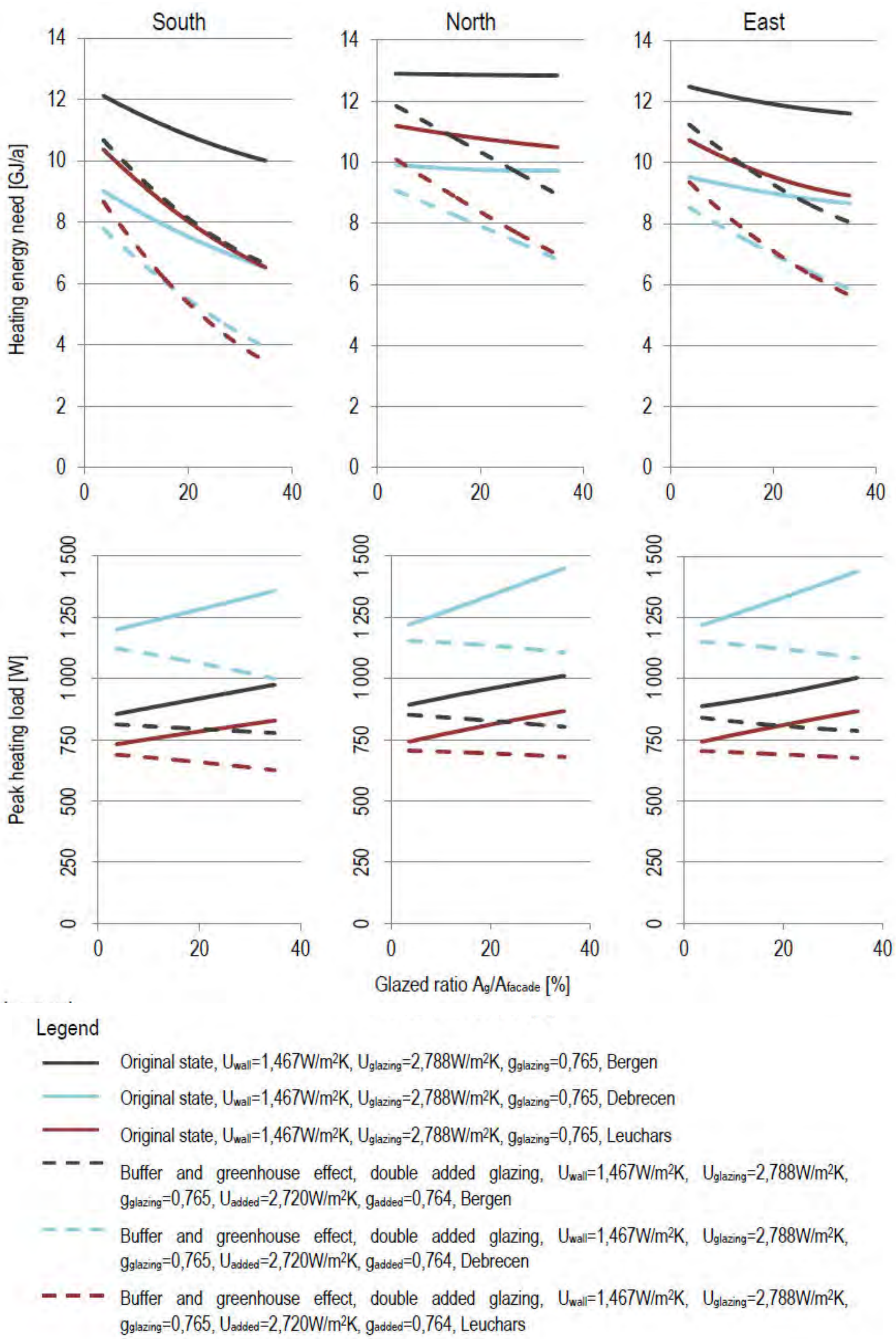

Figure 2. Heating energy need and peak load – original window, buffer and greenhouse effect with added window.

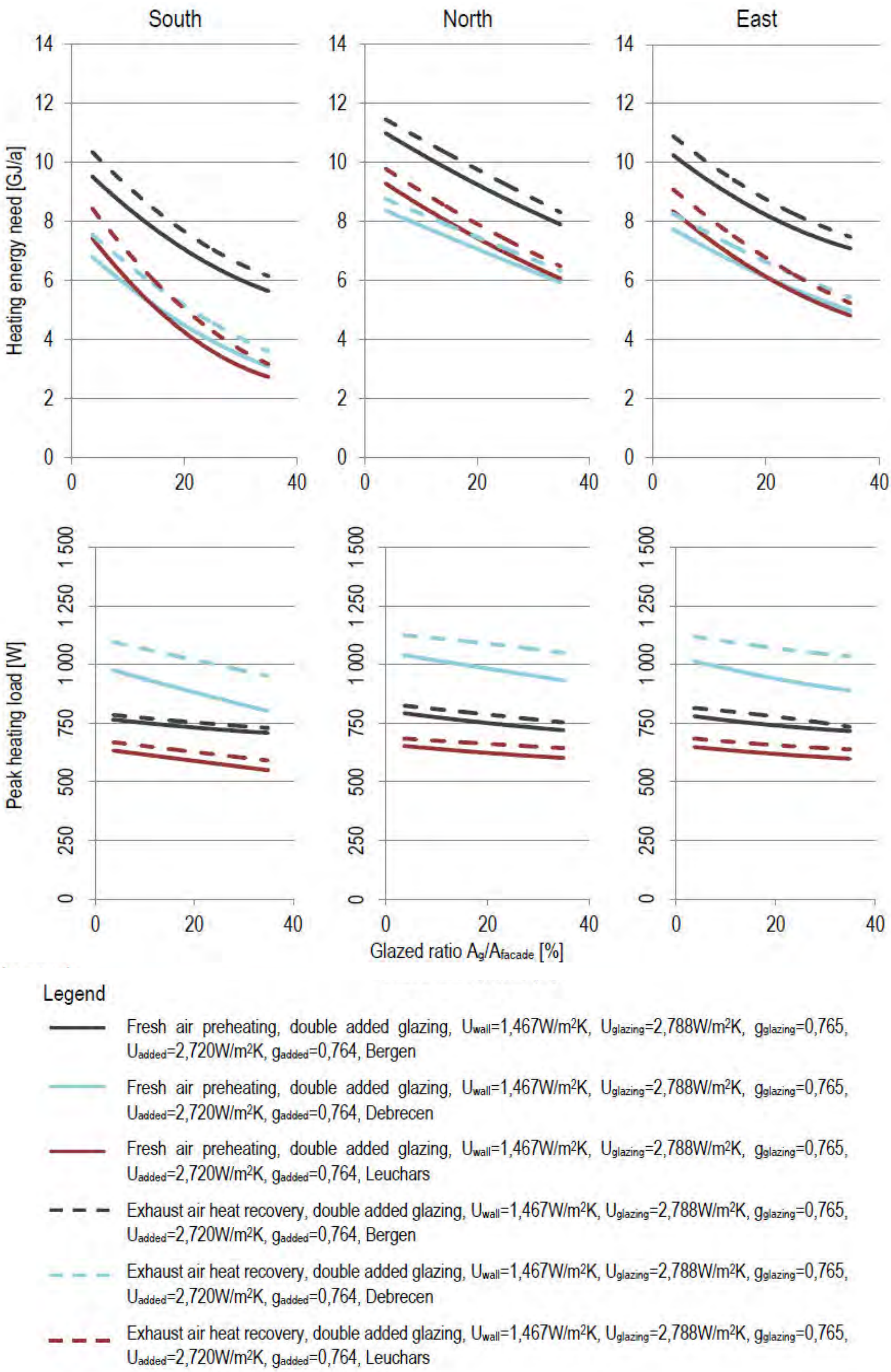

Figure 3. Heating energy need and peak load with different ventilation modes.

Discussion

As far as the latitude is concerned the order of the heating energy need (Fig. 2.) fits the expectation. Positive effects of increasing the glazed ratio of well oriented façades is partly the consequence of the poor thermal insulation of the wall. In the case of the North facing façade the glazed ratio does not practically influence the heating energy need.

Added windows radically decrease the heating energy need. The positive effect of the glazed ratio is more considerable due to several phenomena: the buffer and greenhouse effects, as well as the mass wall gain around the perimeter of the original windows. The higher the glazed ratio is – providing a continuous surface – the less the shadow of the reveals is.

Not surprisingly, the increased glazed ratio is accompanied with higher peak load. This fact traces back to a basic problem: elementary requirements of regulations (U-values, heat loss coefficients) as well as the everyday design practice encompass the low heating peak load although the most important goal is the low heating energy consumption.

Channelling the ventilation air flow through the buffer zone results in a considerable decrease of heating energy need and peak load. Certainly in the case of natural ventilation the air change rate depends on the users' habits: to facilitate the comparison in each case the conventional minimum ACH has been taken into account. In a building of more rooms and storeys it is impossible to say definitely the direction of the air flow since it depends on the wind and temperature difference, therefore both options have been considered. Their average or as a conservative estimation the less favourable one can be taken into account.

The second building option exhibits slightly different features. The effect of the glazed ratio is less radical – this fact is due to the better thermal performance of the façade and the lower U-value of the wall. Here the heating energy need tends to, or exhibits, a minimum at a given glazed ratio whilst in the case of North facing façades the glazed ratio either has no practical effect or shows a moderate negative tendency. Nevertheless the advantage of the added window is clear in each case.

Regarding this option it is worth mentioning that following the common routine of refurbishment (added external thermal insulation on the wall and change of original windows) the reveal become very deep which results in considerable shading. An added window "collects the passive gain" in front of the outer surface of the insulated wall and makes use of solar energy which does not enter the room directly through the original window.

Conclusions

The concept of ventilated window and double skin façade is not new. Its combination with mass wall and application as an effective refurbishment measure maybe considered as a further contribution, which is free of the problem of demolition and facilitates minimal disturbance of inhabitants.

The performance of ventilated windows is analysed among others by Carlos et al. (2010), Appelfeld-Svensen (2011). Simulations, measurements on site and in laboratory prove that the use of a passive elements like the added convex window as a heat recovery is promising. Certainly, the referred authors did not analyse the influence of different climatic zones.

Mainz and Menti (2012) investigated the thermal performance of different glazings itself under different conditions, illustrating the wide variety of positive and negative seasonal balances. They implemented a “climate severity index” – which is the ratio of the degree days and the global radiation income for the same interval. (it is considered a simplified version of that implemented by Santamouris (2010)).

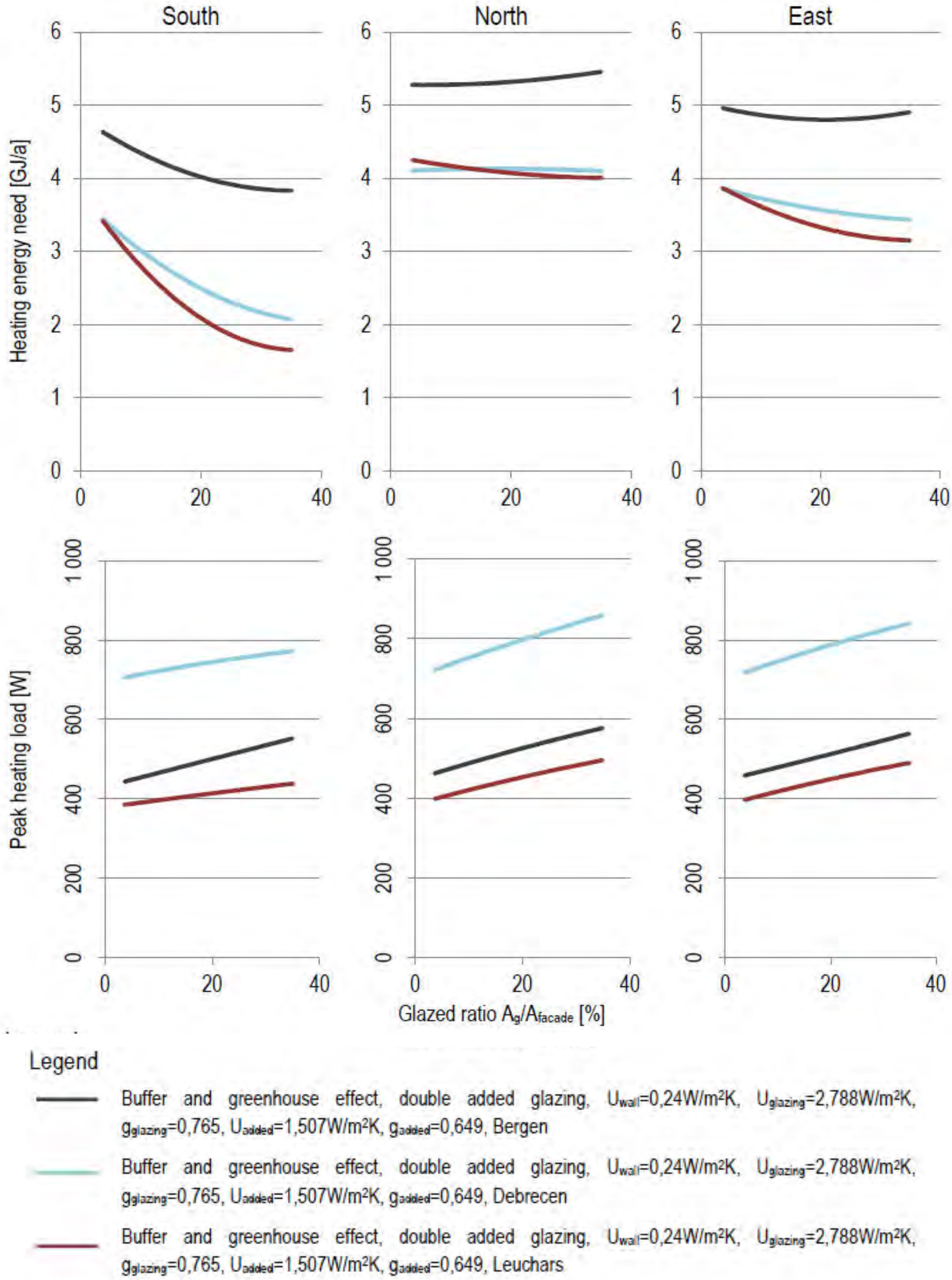

Figure 4. Heating energy need and peak load – buffer and greenhouse effect.

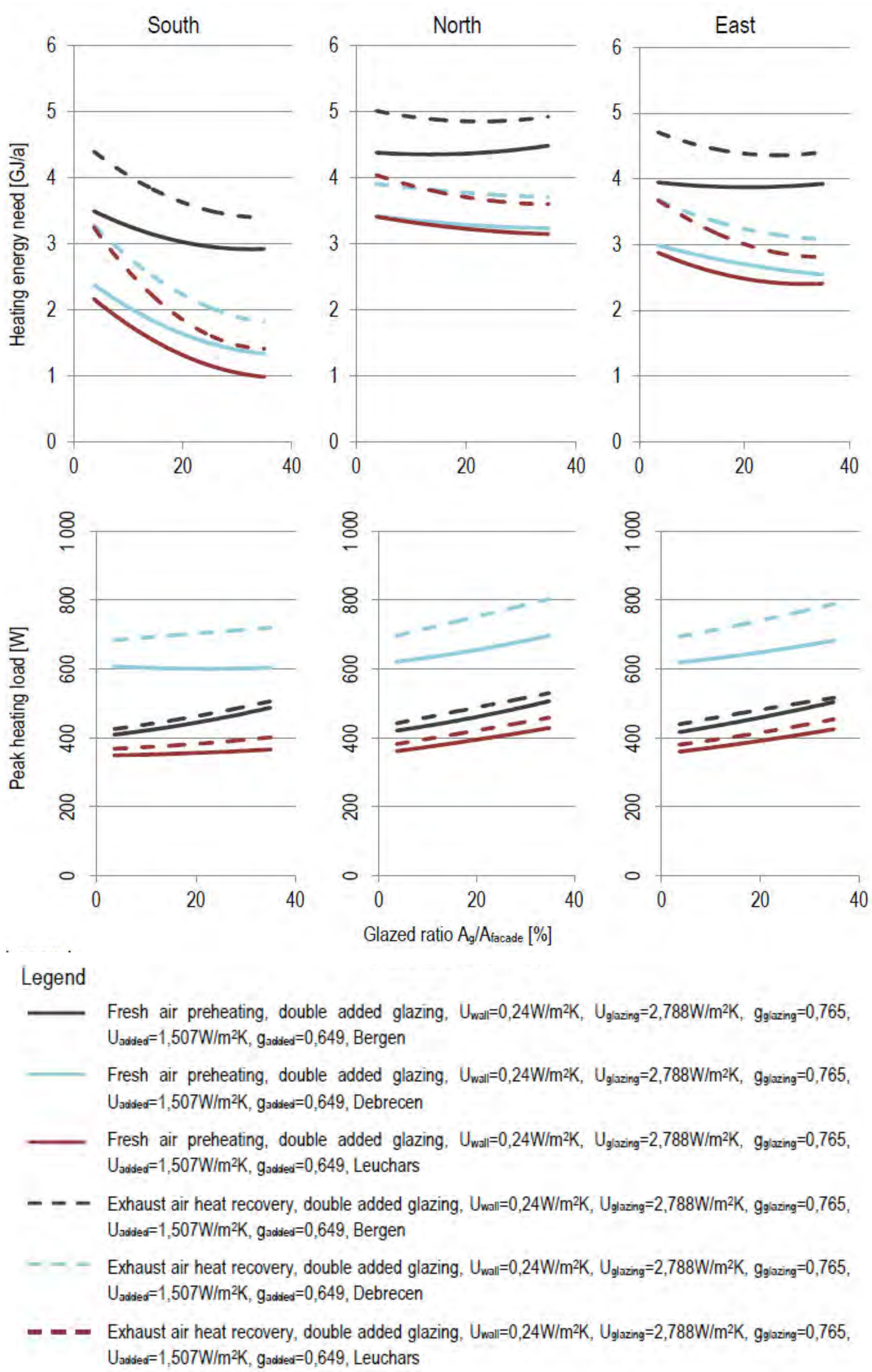

Figure 5. Heating energy need and peak load with different ventilation modes.

The simplified climate severity index does not reflect the many radical or fine differences between the climatic zones proved in our results. Therefore we must take into consideration the following aspects:

First of all for the same location different indices should be applied for different orientations if vertical façades are spoken of.

Secondly if the degree-days are the same for two locations their “length” (from date to date of the traditional heating season) as well as the minimum outdoor temperature can be different (compare Debrecen in Dfb zone and Bergen in Cfb zone). With a mild minimum temperature the longer the “heating season”, the more solar gain can be utilised. The same applies to the effect of the internal gain.

Thirdly further fine differences can be due to the sunpath: the higher the latitude is the closer is the angle of the direct solar beam to the wall azimuth: the higher is the transmitted solar energy and the less is the shadow of the reveal. Another fine side effect is the albedo of the surrounding environment with or without snow.

The results illustrate the potential of passive solar measures. Even if the new concepts of “Passivhaus” and its mutations from passive to active buildings offer new materials and technologies the classic passive solar architecture is not outdated at all. Moreover, if low operational energy consumption is achieved with more and more embodied energy it is worthwhile to set new systems and materials with their embodied energy against the thorough pondering of form, glazed ratio, orientation, to set demolition and replacement against added passive elements of long physical lifetime.

To prevent any misinterpretation the author does not deny the necessity of contemporary technology: the well balanced alloy of old and new ideas offers the best solution.

High-level EU documents neglect utilised passive solar gain. Whilst the Energy Performance of Building Directive encompasses the low operational energy need and requests the utilisation of renewable energy the positive contribution of passive solar systems is not acknowledged in the energy balance as a part of the renewable share.

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Development of Bioclimatic passive design strategies for a composite Indian climate using a newly developed climate analysis tool

Naveen Kishore Khambadkone[1] and Rekha Jain[2]

[1] Research scholar, Department of Architecture and Planning, Maulana Azad National Institute of Technology (MANIT), Bhopal, M.P. India. E-mail:knaveen.edu@gmail.com
[2] Professor, Department of Architecture and Planning, Maulana Azad National Institute of Technology (MANIT), Bhopal, M.P. India. E-mail:rekha.manit@gmail.com

Abstract: This paper aims to examine the potential for improving thermal comfort for a location under composite climate zone in India through bioclimatic analysis. A new bioclimatic tool has been developed for the investigation of the potential of passive heating and cooling strategies. A modified thermal comfort zone is proposed for a composite climate based on a review of the recent thermal comfort field surveys carried out in India. The comfort zone of the chart was then extended to define the control potential zones (CPZ's) or passive design zones based on the calculations of the effects of passive heating and cooling strategies. The hourly weather data based on TMY (Typical Meteorological Year) was used for the climate analysis. The bioclimatic potential of three passive strategies, namely Natural Ventilation, Direct Evaporative Cooling and Passive Solar Heating have been analyzed for their thermal comfort potential. Results show that Natural ventilation has the maximum potential (71 %) for achieving comfort in a composite climate of India. Location specific passive strategies can be developed using this tool based on the severity of the climate with in a composite climate zone in India.

Keywords: Passive strategies, Passive design potential, Bioclimatic chart, Composite climate, India.

Introduction

One of the primary goals of a sustainable built environment is to design buildings which are sensitive to the local climate. A full understanding of the local climate provides the designer with the opportunity to explore the possibilities of a range of passive design strategies which are contextual to the location of the building. In this study a simple tool is developed for climate analysis, tailor made for people living in the composite climatic zone of India. The presently available climate analysis tools like weather tool (Ecotect weather tool, 2011) and climate consultant (Climate consultant, 2011) are primarily designed for temperate and cold climates where people are acclimatized to such climates and hence tend to employ HVAC systems more frequently to achieve indoor comfort. In contrast, people in tropical climates mostly live in naturally ventilated buildings where varying range of indoor conditions are experienced due to changing outdoor conditions. The occupants in such climates adapt themselves through behavioural, psychological and physiological controls to achieve acceptable comfort conditions indoors. The adaptive model of thermal comfort, used in international standards like ASHRAE Standard 55 2013 is based on this fundamental premise. It is hence logical to expect that the comfort requirements of occupants are also likely to vary significantly in these climates when compared to temperate and cold climates. This paper presents a simple and easy to use climate analysis tool which can be used by architects and building designers to get an overall picture of the potential for comfort achievable and the passive strategies appropriate for a location under composite climatic zone in India. The city of Bhopal, which is classified under the composite climatic zone (NBC, 2005) is taken as a case study. The proposed method for developing the tool was carried out in the below mentioned steps:

i) Analysis of comfort requirements and definition of an appropriate thermal comfort zone on the bio climatic chart for people living in the composite climate of India.

ii) Definition of control potential zones (CPZ) or passive design zones as extensions of the base comfort zone.

iii) Quantitative analysis and assessment of thermal comfort, heating and cooling potential of different passive strategies. This will be done for the whole cumulative year and individual months.

Thermal comfort zone for people living in composite climate of India

International standards like ASHRAE (ASHRAE Standard 55, 2013) in their 'Graphical comfort zone method' section propose a conventional comfort zone on the psychrometric chart uniformly applicable to all climates in the world. This is based on the PMV-PPD index. Particularly the upper humidity ratio limit of 0.012 Kg (water vapour)/kg (dry air) is very restrictive for tropical climates. However some earlier studies (Nicol, 1974) in tropical regions and recent field studies on thermal comfort in India (Indraganti, 2010), (Dhaka, 2015) particularly in a composite climate, have questioned the applicability of the ASHRAE thermal comfort Standards in these regions. These studies have shown that people have higher thermal acceptability or tolerance than what is defined in the international standards like ASHRAE Std 55 (ASHRAE Standard 55, 2013). This is due to the adaptation of the subjects to higher temperatures in a warm climate. Hence the international standards may not be directly applicable to Indian conditions.

The computer weather tools like Ecotect weather tool and climate consultant also fail to predict the comfort periods for Indian conditions because they use comfort boundaries which are defined by ASHRAE standards or comfort models suited to temperate and cold climates. For example Figure 1 shows the comfort prediction by two weather analysis tools, namely climate consultant and Ecotect weather tool.

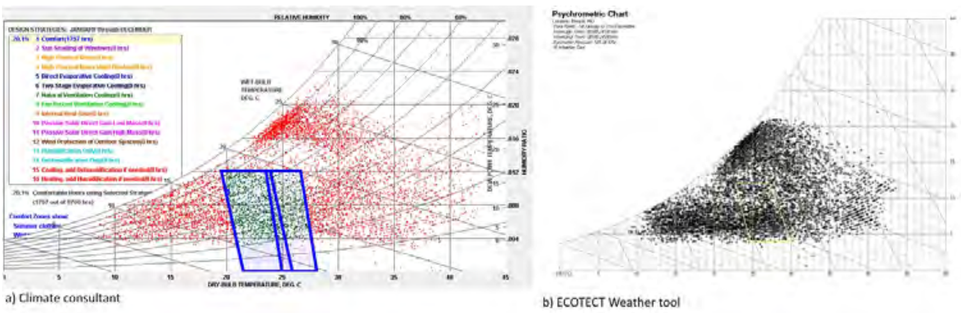

Figure 1. Comfort predictions for Bhopal by a) Climate consultant and b) Ecotect weather tool.

The comfort zone proposed for Bhopal using climate consultant tool is based on the ASHRAE standard 55 2004 and it shows that it is only possible to achieve comfort conditions for 20 % of the total time in a year. A similar prediction is shown by the weather tool, which indicates that only 20 % of the total time in a year is comfortable. But according to certain recently conducted thermal comfort field surveys in India (Dhaka, 2015) it was found that more than 80% of the people living in naturally ventilated buildings voted with in the comfort band (-1,0,+1) which represents 80 % acceptability according to the International standards of thermal comfort. These comfort percentages of satisfied people in the tropical climate of India indicate that the predictions of computer tools significantly underestimate the actual comfort potential of composite climates in India.

Table 1 gives a summary of the recently conducted field studies on thermal comfort in India. The studies show that occupants living in naturally ventilated buildings in a composite climate of India adapted themselves to the varying outdoor conditions and kept themselves comfortable through various adaptive actions like opening of windows, turning on fans, change of clothing as per season, changing of activity levels, etc in a wide range of comfort temperature between 17 °C to 35 °C, relative humidity between 15 % - 90% and air speeds between 0 – 1.5 m/s. This indicates a wider comfort band higher than what is defined in the international comfort standards as well as Indian standards.

Table 1 Thermal comfort field studies in composite climate-India.

Climatic zone (Location)	Season	Year	Building type	OPERATIVE TEMPERATURE			Author /Reference
				Comfort bandwidth (80 % acceptability)	Neutral Temperature (in °C)	Thermal sensation -Comfort band votes in %	
Composite (Hyderabad, India)	Summer-May	2008 - 2010	Residential (NV)	26 °C - 32.45 °C	29.23 °C	40	Indraganti et al.
	Monsoon-June					87	
	Monsoon -July					94	
Composite (Hyderabad, India)	All seasons	2014	Offices (NV)	22.4 °C - 30.2°C	28.0 °C	NA	Indraganti et.al
Composite (Jaipur, India)	Summer	2015	Residential and student hostels (NV)	16.7 °C - 34.8°C	29.4 °C	76.1	S.Dhaka et al.
	Monsoon				27.0 °C		
	Winter				25.64 °C		
Composite (Jaipur, India)	Summer	2016	Residential and student hostels (NV)	25.2 °C - 30.6°C	27.9 °C	79%	S.Kumar et al.
	Monsoon					92%	
	Winter					70%	

Methodology

In this paper, a revised thermal comfort zone is proposed on the building bio climatic chart for people living in the composite climate of India. This comfort zone is defined as the Adaptive comfort zone (ACZ) which defines the acceptability limits of comfort for people living in naturally ventilated buildings in a composite climate. This ACZ also takes into account the various behavioural adaptations like acceptable operative temperature limit, humidity limits, clothing, activity and air velocity preferences for people living in a composite climate in India. Figure 2 shows the newly defined (modified) thermal comfort zone (thick lines) for a composite climate. The comfort zone applies for normal healthy

Indians for sedentary work (Standing, relaxed- 1.2 met – 70 W/m^2), under still air conditions (0.2 m/s). The clothing insulation values vary from 0.5 clo -1.0 clo reflecting the adaptation of people as per change of seasons, from summer to winter. The thermal conditions inside this comfort zone is expected to satisfy 80 % occupants based on 10 % predicted whole body dissatisfaction and 10 % dissatisfaction due to local discomfort like cold floors, draught and radiant temperature asymmetry. The lower limit of humidity is set at 20 % because Indian people living in composite climate do experience dryness of skin, nose, throat and eye irritation during the hot-dry months (April and May). This has also been substantiated through the recent field surveys (Indraganti, 2010). The upper humidity limit for this comfort zone is fixed at 80% for still air conditions (0-0.2 m/s), because at humidity levels higher than this, lack of air movement may cause stuffiness and cause discomfort due to skin wettedness, especially at temperatures higher than 32 ^{o} C limit or the skin temperature (Indraganti, 2010). Moreover under still air conditions (0-0.2 m/s), it was found that the occupants in naturally ventilated buildings were comfortable up to a lower temperature limit of 18 ^{o} C and a higher temperature limit of 32 ^{o} C for 80 % acceptability (Kumar et al, 2016). Thus, based on the review of thermal comfort surveys (Table 1) it is found that the occupants living in naturally ventilated buildings in a composite climate of India are comfortable in a range of operative temperature between 18 °C to 32 °C, at relative humidity between 20 % - 80% under still air conditions (0 – 0.2 m/s). This defines the adaptive comfort zone for a composite climate of India.

Control potential zones for passive cooling and heating strategies

This study considers only the *direct* passive cooling and heating strategies namely, *Natural ventilation, Direct evaporative cooling* and *Passive solar heating*, as they are directly related to the climate variables, namely *wind speed*, *humidity* and *solar radiation*. The indirect strategies like thermal mass and mass with night purge ventilation, indirect passive solar heating and indirect evaporative cooling are not considered, as these are highly influenced by parameters like building envelope thermal properties, occupancy and equipments.

Passive cooling by Natural ventilation

The two most important functions of air movement are to enhance convective and evaporative heat loss. Convective heat loss by air movement is effective when the air temperature is near to or less than the skin temperature at lighter clothing levels (0.5 clo). Above skin temperature, air movement causes discomfort due to heat gain on body surface. This phenomenon was observed in Hyderabad (Indraganti, 2010). Evaporative heat loss is most effective at medium humidity levels between 40-50% and at air temperatures near or below skin temperature (32 °C). At higher air temperature, higher humidity levels (> 80%) impede evaporation and hence cause discomfort. In such a case higher air velocities (1.0 m/s or higher) are favourable in reducing discomfort. As discussed before, it has been observed especially during summer months (Kumar et al, 2016) that subjects wearing lighter clothing (mean 0.3 clo) adapted themselves comfortably by opening windows and using ceiling fans at lower speeds to achieve moderate air movement of up to 0.5 m/s at temperatures as high as 33 °C and relative humidity between 20- 80%. Further it was also observed that the subjects' desire for higher air speeds increased with increasing indoor operative temperatures. At temperatures higher than 33°C and up to 35 °C, the subjects' preferred an air speed of 1.0 m/s or higher. Figure 2 shows the extended passive zone through natural ventilation as dotted lines. The upper limit of this zone extends up to an operative temperature of 35 °C. At higher humidity levels thermal comfort sensation is experienced at lower operative temperatures. Hence this is shown along a tilted line which follows the SET temperature line on the Bio climatic building chart. This corresponds to an air velocity limit of up to 1- 1.5 m/s. Beyond this limit air movements cause discomfort due to heat gain on body surface, draughts and paper blowing.

Passive cooling by direct evaporation

Evaporation is the process which converts sensible heat into latent heat by increasing the water vapour content in dry air. The most important parameters which govern this strategy are the Wet bulb temperature (WBT) and the wet bulb depression i.e. the difference between the maximum dry bulb temperature and maximum wet bulb temperature. The higher the wet bulb depression higher is the cooling effectiveness of evaporation. But during this process the wet bulb temperature remains unchanged. In a composite climate in India, humidity is generally low (30 % or less) during the day time in the hot dry season (Latter half of March, April and May). Hence this strategy is most effective during this season. The cooling performance of a direct evaporative cooling system is measured by the air temperature exiting the evaporative cooler and is given by the following relation:

$$T_{EC} = T_{DBT} - T_{WBD} \times \varepsilon \qquad (1)$$

Where T_{EC} – is the Air temperature exiting the cooler (in °C); T_{DBT} – is the Ambient inlet dry bulb temperature (in °C); T_{WBD} – is the wet bulb depression (T_{DBT} - T_{WBT}) (in °C); ε is the efficiency of the evaporative cooler. In a direct evaporative cooling system the ambient air temperature is reduced by nearly 70-80% of the wet bulb depression (Givoni, 1992). Based on this the maximum limit of outdoor ambient air temperature for achieving comfort by means of direct evaporative cooling is fixed at 42 °C for hot dry climates. The corresponding wet bulb temperature would be a maximum of 22 °C. This would give an indoor cooling temperature from the evaporative cooler between 26-27 °C at a mean indoor air temperature of 27-29°C (Givoni, 1992). The maximum limit up to which dry bulb temperature can be lowered by direct evaporative cooling is about 11°C (Szokolay, 2004). Thus the upper comfort limit for the evaporative cooling zone is extended by 11 °C along the wet bulb temperature line.

Passive solar heating

This strategy is applicable in the cooler season of the year. It relies on direct solar heat gain through fenestrations. To get an approximate idea of the effectiveness of a passive solar system, a building energy balance and steady state heat transfer model is used. Assuming a typical south facing wall of area 35 sq.m. (10 m x 3.5 m) of an office building on a middle upper floor having a floor area of 100 sq.m, with window area of 10 sq.m (2 m x 5 m) with no internal heat gain or heat exchanges with adjacent spaces, the heat flow through south wall, window and infiltration (ventilation) heat gain is given by the below equations:
Heat flow through south wall is given by:

$$Q_{wa} = U_{wa} * A_{wa} * (T_i - T_{so}) \qquad (2)$$

T_{so} is the Solar air temperature, which is given by: $T_{so} = \mathrm{To} + \frac{\mathrm{Is \times \alpha}}{\mathrm{ho}}$ (3)

Heat flow through window opening is given by (ASHRAE handbook of fundamentals, 2009):

$$Q_{wi} = (SHGC * I_s * A_{wi}) + [U_{wi} * A_{wi} * (T_i - T_o)] \qquad (4)$$

Heat gain due to infiltration is given by:

$Q_v = \rho * C * V_r * (T_i - T_o)$ (5)

Where,
U_{wa} is Overall thermal transfer co-efficient (U value) through the south wall in W/m^2 º C,
A_{wa} is the area of south external wall in m^2,
α is the solar absorption coefficient of the external wall,
h_o is the outside surface film heat transfer co efficient of the external wall surface,
SHGC is the Solar Heat Gain Coefficient of the window glazing (dimensionless),
I_s is the mean daily solar irradiance on the south facing wall in the coldest month in Bhopal,
U_{wi} is Overall thermal transfer co-efficient (U value) through the window,
A_{wi} is the area of the window in m^2,
ρ is density of air in Kg/m^3,
C is specific heat of air (J/ kg ºC),
V_r is ventilation rate (m^3/s) and T_i is the Indoor air temperature, T_o is outdoor ambient air temperature. The steady state heat transfer equation for energy balance of the space is given by (omitting evaporation heat loss on roof surface):

$Q_{wi} - Q_{wa} - Q_v = 0$ (6)

Assuming a conventional construction in India which is made of an RCC framed structure with: i) External wall: 190 mm modular brick with 12 mm plaster (outside and inside) with a U_{wa} value of 2.35 W/m^2 º C with α = 0.6, h_o= 22.7 W/m^2 º C
ii) Window: Aluminium framed with 6 mm single glazing having a U_{wi} value of 5.7 W/m^2 º C and SHGC of 0.7
iii) For ventilation, considering an air exchange rate of 2 hr^{-1} and volume of space-V=350 m^3 (10m x 10m x 3.5m)

The indoor air temperature at the lower limit of the comfort zone is 18.0 º C at 50% Relative humidity. The average daily solar irradiance on the south facing wall in the coldest month in Bhopal is 207.5 W/m^2. On calculation, this gives a T_o value of 13.9 º C, which is the lowest outdoor temperature at which the heat delivered by a passive solar system can compensate to maintain indoor comfort temperature. Below this temperature, active heating systems would have to be used. It is important to mention that the actual efficiency of the passive solar system depends on the building design and envelope specifications, type and design variables of the passive solar system. Therefore the above model considers standard conditions and hence is only for a reference.

Plotting of hourly climatic data on bioclimatic chart

Figure 2 shows the hourly conditions for a typical meteorological year for Bhopal. This chart is created using a newly developed bio climatic analysis tool in an excel spreadsheet. Each point represents its x-coordinate (Dry bulb temperature) and y-coordinate (Humidity ratio). The number of data points were identified with in each of the boundaries (comfort and passive design) using IF-AND logic in the excel spreadsheet. Based on the number of points identified with in a given boundary, the potential for comfort and passive heating and cooling was calculated.

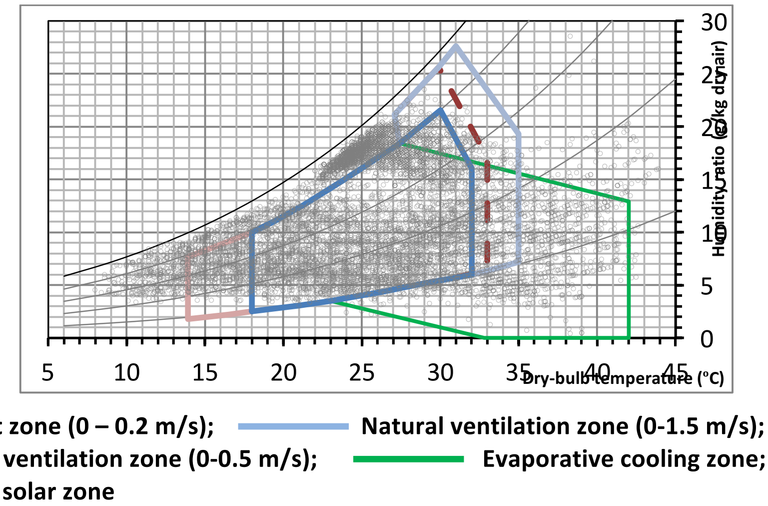

Figure 2. Plot of hourly weather data points for Bhopal at standard atmospheric pressure (101.325 kPa)

Results

Cumulative whole year assessment

The cumulative comfort potential of different passive design strategies (in percentages) for the whole year is shown in Figure 3. Natural comfort, *without* the use of any passive strategies can be achieved for nearly about 49% of the total time of the year. The percentage of comfort improvement for each passive strategy is also shown in Figure 3. Natural ventilation proves to be the *most effective* passive technique for comfort improvement (21.5 %). This correlates well with the field studies (Indraganti, 2010), (Dhaka, 2015) where occupants used adaptive measures like opening windows and turning on ceiling fans to achieve comfort. The comfort period can be increased by this strategy and it provides a cumulative comfort (70.6 %) for more than half period of the total time during a year. Passive solar heating (6.3 %) (Cooler season) and direct evaporative cooling (4.2%) (Hot-dry season) are less effective because they are season dependant. Nearly 81% of the total time during a year would be thermally comfortable if *all* three strategies are combined.

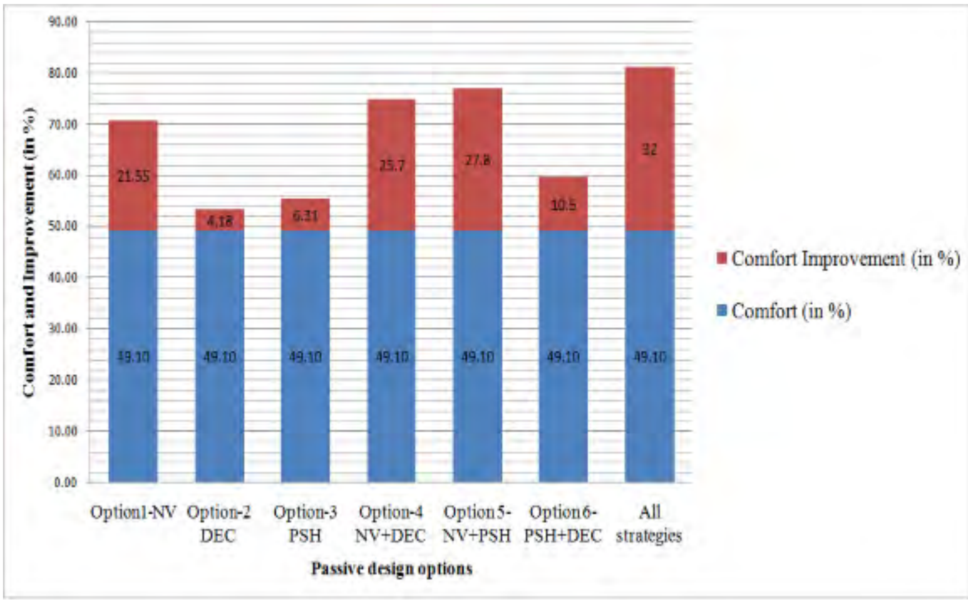

Figure 3. Cumulative and Potential for comfort improvement for each passive strategy and their combinations for the whole year in Bhopal (in %).
Natural Ventilation (NV), Direct evaporative cooling (DEC) and Passive solar heating (PSH).

Conclusions

This study illustrates through a simple tool, a method to analyze the composite climate in the preliminary stage of climate responsive building design. This method gives reliable results and is very useful for the architects and building designers to get a very quick summary of the climate of any location within a composite climate zone in India. It is important for architects using software tools to have a thorough understanding of the local climate for designing climate responsive buildings. Three passive strategies related to the climate were explored in this study. But relying completely on these passive strategies to maintain thermal comfort is not feasible, although still there is a significant potential for improvement of comfort. The actual comfort conditions achieved will be contextual and depend on the building typology and its building envelope design specifications. Natural ventilation proves to be the *most effective* passive design strategy for achieving thermal comfort in a composite climate of India. This correlates well with the recently conducted thermal comfort field studies in a composite Indian climate. Being a low and cost effective strategy, its applicability must be explored through more detailed studies particularly for free running (unconditioned) buildings. More such locations need to be analysed under a composite climate in order to investigate the applicability of a particular passive strategy based on its climate severity.

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Performance Comparison of Heat Exchanger Using Water and Sand for the Evaporatif Cooling Roof: An Experimental Research

Jefrey Kindangen[1] **and Markus Umboh**[2]

[1]Architectural Engineering Department, Faculty of Engineering, University of Sam Ratulangi, Manado, Indonesia, Jl. Kampus Unsrat, jkindangen@yahoo.com
[2]Mechanical Engineering Department, Faculty of Engineering, University of Sam Ratulangi, Manado, Indonesia, Jl. Kampus Unsrat, markus_umboh@yahoo.com

Abstract: This study aims to investigate and compare the performance of a heat exchanger using water and sand in a hot and humid climate of Indonesia. The heat exchanger consists of copper cooling coil with a size 3/4' of diameter that arranged and buried as deep as 10 cm in an acrylic container measuring 1 x 1 x 0.2 m, which filled with water or sand. Water from the zinc roof surface after spraying was accommodated in the gutters then flowed to the heat exchanger. The comparison of performance from a heat exchanger using water and sand shows that both water and sand has not much different performance to decrease the water temperature through it. The heat exchanger using either water or sand as cooling medium can decrease the temperature of the incoming water after being sprayed on the roof surface by about 0.8°C in average. As the cooling medium, the mean temperature of the water and sand is not much dissimilar from each other, each about 27.5°C. It is necessary to mention that the power of the heat exchanger using water to cool the incoming water is more effective in the forenoon, while the sand being effective occur at noon and afternoon. Essentially, this system has demonstrated its usefulness and capacity as a passive cooling strategy for improving thermal comfort in the humid tropics.

Keywords: passive cooling, evaporative cooling roof, heat exchanger with water or sand, roof surface temperature

Introduction

Buildings face the problem of excessive heating as an upshot of the pressing of hot and humid climate. This condition will result inconvenience of occupants and a waste of energy for cooling the room if not taken seriously. Energy consumption will increase when the construction was designed unconsidered environmental conditions, use of construction materials inappropriately and ignores the protection from direct sunshine. Building on average in humid tropical climates face the problem of how to maintain comfortable conditions in the buildings.

The passive cooling strategy is a scheme for economising energy consumption and achieving thermal comfort that needed for a tropical humid climate condition. The evaporative cooling that being ignored in the region is as one of the passive cooling strategies. Implementation of this plan will be able to conserve energy needs of the building and make a comfortable space condition and efforts to lower the cooling load drastically. It is essential for creating a comfortable place that will increase the productivity of the occupants of the buildings.

The evaporative roof spray cooling system is not a new idea; studies have been done since early 1939. Because of the energy crisis, roof spray cooling methods have recently become acceptable and desirable (Carraso et al, 1987). The operation of roof spray cooling is a straightforward and fundamental one; the basic concept aims to wet the hot surface and cool it down with sprayed water. Maerafat et al. (2010) have studied the role of the evaporative cooling cavity in residences; they reasoned that the application is successful and get a broad impact on cooling strategies. Givoni (2011) and Joudi and Mehdi (2000) examine the indirect evaporative cooling with a cooling load varies for housing, they have concluded that the passive cooling system can reduce the room temperature, but this system will differ from one another depending on the particular climate. Kim et al. (2011) have examined the potential energy savings with direct or indirect evaporative cooling by using the outdoor breeze and concluded both these strategies could be utilized for the energy conservation.

Jain et al. (2008) have tested the insulation along the roof of the building that can be customized for the intention of cooling by using an indoor air or not which demonstrated this arrangement can work in the right way. In 1977, they had also experimentally investigated in some detail the issue of roof pond and roof spray at the roof surface of a thick reinforced concrete roof exposed to a hot-day sunny climate. It was found that, by roof shower, the peak roof temperature decreased from 55°C to 28°C as compared to a reduction from 55°C to 32°C in the case of roof pond. The condition was obviously due to more efficient evaporation of water at the roof surface. The roof surface temperature was observed to undergo a drop of the order of 15°C as compared to 13°C in the case of the water pond.

Kettleborough et al. (1981) have conducted research on how the wet plastic plate as a heat exchanger was performed for indirect evaporative cooling. Likewise, Costelloe and Finn (2003) stated that the passive cooling with the air-water system is potentially applied in temperate or moderate climates. Tang et al. (2005) have described that the cooling with a puddle on the roof using a floating bag had good performance compared with movable insulation. Wongsuwan et al. (2006) have conducted an experimental study on the roof pond house under tropical climatic conditions; they concluded that the system could reduce 2-4°C indoor temperature lower than the outdoor.

Spanaki (2007) had reviewed the literature of some studies on the different type of roof ponds for cooling purposes; she reported that spraying system is usually preferred for larger cooling loads. The usefulness of roof spray-cooling was found to be most useful in buildings with lightly constructed, poorly insulated roofs. In relatively the same line with research of Zhou et al. (2004) that studied the effect of the difference between a grass roof and the roof by spraying water in a building with reinforced concrete (RC) construction. The conclusion is that the roof by spraying water is not suitable for an RC building with a high level of insulation in the roof. Kindangen (2016) has reported that water spraying can reduce the zinc roof surface temperature by an average of 5°C and to gain a greater advantage of the roof temperature reduction is needed to spray water in approximately 10-15 minutes and carried on continuing.

All of these studies as described, they noticed generally how evaporative cooling was applied to the roof of the building, but this brings up another problem: how to make the water after being sprayed being cooler for reuse. Water after being sprayed will be hotter, to reuse it required the cooling process in order to cooling by spraying more effective. Re-cooling can be answered by applying a heat exchanger. The purpose of this paper is to compare the performance of a heat exchanger using water and sand.

Methods

The experiment has taken out in Manado city, it is situated in the state of North Sulawesi in Indonesia, at latitude 1.4583°N and longitude 124.8260°E, has a humid tropical climate. The hottest month is August with average temperature 27°C and the coldest one is January with average temperature 25.9°C. In general, the temperature difference between the hottest and the coldest month is not too much; their amplitude is low. The rains' period occurs from November to February, being the rainiest month January (452 mm).

A cell test was constructed with a 1.5 m of length, 1.5 m of width and 2.5 m of height with plywood for the walls and floor and the roof made of corrugated zinc sheets. The floor cell test made of plywood that raised about 80 cm from the ground. This construction does not have a ceiling; roof tilted only in one direction. The cell has openings measuring 30 x 40 cm on the right and left sides (North and South) as presented in figure 1. The house test is placed outdoors, in the garden, as efficiently as possible exposed to direct sunlight in the morning until the afternoon.

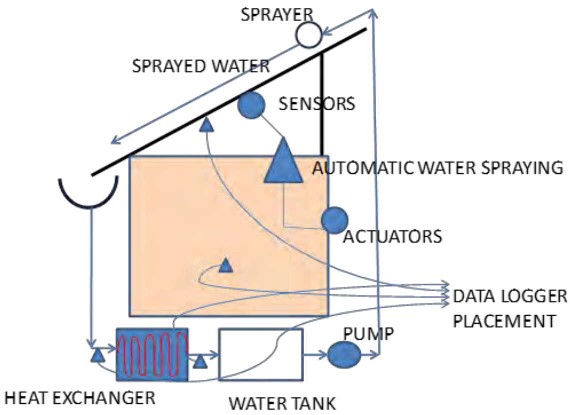

Figure 1. A cell test and schematic design of cooling roof device.

Measures were taken to check the performance of the heat exchanger using RC-4HC data logger that measures temperature and relative humidity. We use 5 pieces RC-4HC data logger with the appropriate placement. One data logger is placed in roof gutters that take in water after spraying, is given as a reference temperature of incoming water where the temperature must have been hotter. One data logger is ready at the end of the copper pipe to record changes in water temperature coming out of the heat exchanger. A data logger to record the temperature of the water or sand in the heat exchanger as a cooling medium. A data logger is placed in the cell test for recording the temperature in the room and other data logger is placed and affixed to the inside of the zinc roof to measure and record the temperature of the roof surface.

A heat exchanger made of acrylic plates with a size of 1 x 1 x 0.2 m. The copper pipe is used as a cooling coil with a size 3/4' of diameter and 6.5 m of length mounted in an acrylic box. An acrylic box filled with water or sand as a coolant in which the copper pipe buried as high as about 10 cm from the surface of the water or sand. At the terminal of the copper pipe where the water will be provided with a plastic hose to the tank. The circulation water is pumped out of the tank with a submersible pump capacity of 4000 l/h. Water is pumped into the perforated PVC pipe on one side that will squirt water onto the entire surface of the roof.

An automatic roof spraying device was designed and it consists of a controller, sensors, and actuators. The microcontroller Arduino UNO and SSR 25-DA require a supply voltage of

12V to the electrical current of 3A, while DHT11 and DS18B20 sensor probe and a 2x16 LCD need a supply voltage of 5V. The DHT11 sensor is applied to observe the roof surface temperature while the DS18B20 sensor probe is utilized to assess the indoor air temperature. These sensors are really easy to use with the microcontroller Arduino, and they have an excellent point of stability and very precise calibration.

The device is set at a certain temperature as a parameter of the roof surface temperature limit. If the limit exceeds, then the controller will activate the actuator and the pump will work to spray water on the roof. Exactly the same, if the temperature of the roof is less than or equal to the limit, the controller will turn off the actuator.

Figure 2. The heat exchanger designed: water and sand as media cooling.

Results and Discussion

The temperature parameter was adjusted at 38°C; it means the motor will turn on when the roof temperature reaches 38°C and water will be sprayed. Measurements were carried out in the period of July and October. For the day, the average indoor temperature is lower than the outside temperature. The roof surface temperatures get down to go drastically up at 09:00 and fluctuate until 13:00, and the temperature can shoot from 50 to 56°C. The phenomena caused by the proprieties of metal like zinc: it is easier and faster to absorb and emit the heat. After 15:00, the internal temperatures go down less than the outer ones. The roof surface has always maintained less than 38°C, and given effectively benefits for the daytime. It caused the indoor air temperature is lower than the exterior during the day. In fact, an automatic spraying water onto the roof surface can significantly cut the roof surface temperature, even go down to 14°C.

The next step is investigating the performance of heat exchanger using either water or sand as a cooling medium to reduce the temperature of the water to be reused after spraying the roof surface. Measurements performed at the time the water out of the gutter and into the copper pipe in the heat exchanger, it is called a water-in; while the term of water-out is water that has passed through a heat exchanger, which will be forwarded to the water tank. An expected process occurs in the heat exchanger is cooling the water after the cooling process by spraying the roof surface.

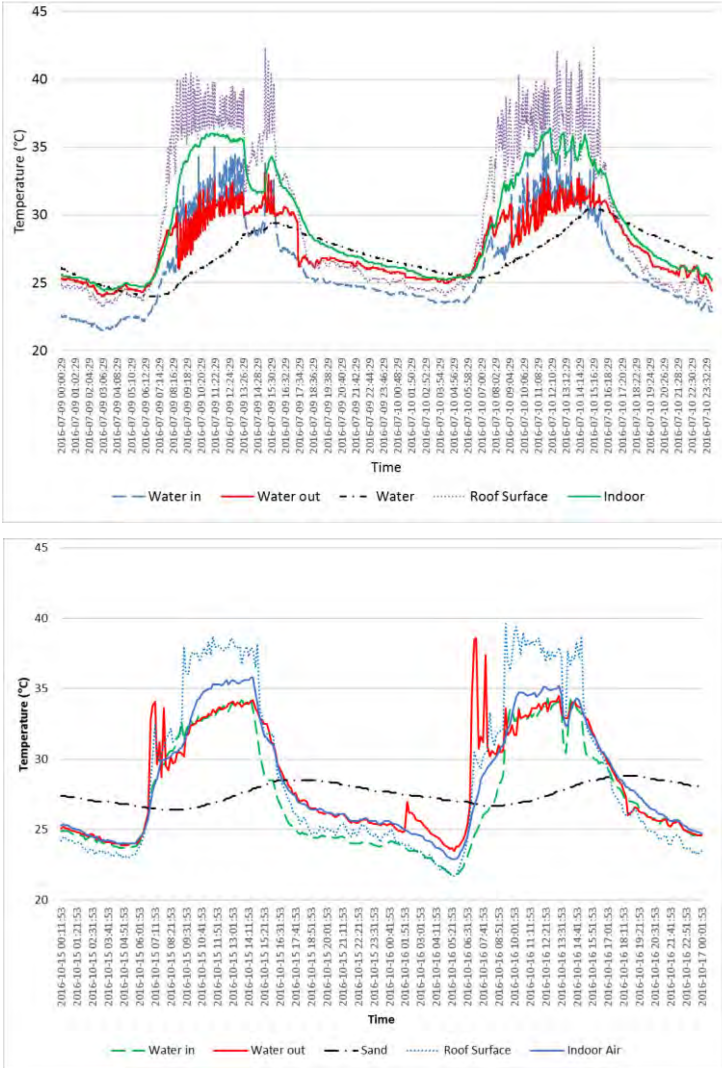

Figure 3. The performance of heat exchanger designed: water and sand as a cooling medium.

Figure 3 shows the state of the water temperature when entering and exit to and from the heat exchanger compared to water or sand temperature in the box of a heat exchanger, the roof surface and indoor temperatures. The roof cooling occurred effectively at 8 am to 3 pm, where the spraying of water occurs not continuously depend on whether they have passed the temperature threshold set or not; the process of cooling water by a heat exchanger also depends on the presence or absence of spraying occurs, thus curves for water-in and -out should not be continuous.

Comparison of water and sand temperature as the cooling medium in the heat exchanger indicates that the water temperature reaches a minimum at 25°C at 06:00 and a maximum of around 30°C at 15:00. While the sand temperature reaches a minimum value at 26°C at 08:00 and a maximum of around 28°C at 17:00. Both characteristics of the two materials, thereby resulting in an average performance are almost similar in the cooling water sprays; but the performance of cooling by water is more optimal occurs at 08:00 to 11:00 compared with the performance by the sand. Performance of cooling by sand more optimal occurs at 11:00 and so on, as presented in figure 4. This phenomenon is also reinforced by comparing the indoor air temperature between the cooling by water and by sand as illustrated in figure 3. The decreasing of roof temperature, on average, it is more effectively occurred in the cooling by sand.

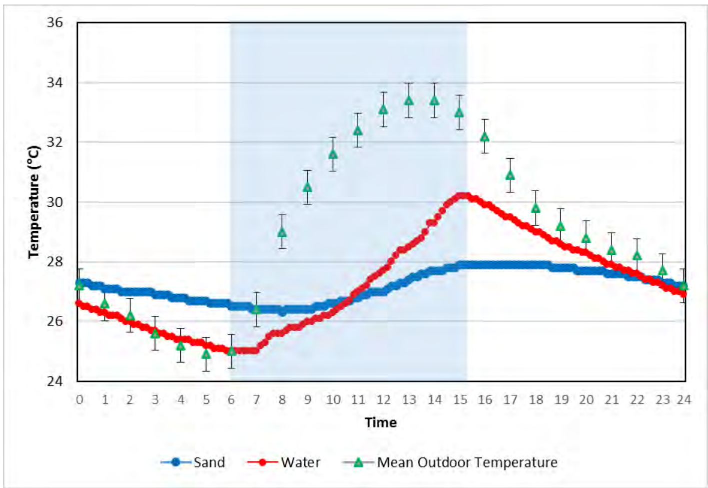

Figure 4. Sand and Water temperatures as water cooler of heat exchanger vs mean outdoor temperature

For more details, we sort out suitable data as in figure 5, it demonstrates the comparing of the temperature of the water-in and -out from a heat exchanger; the difference between them amounted to an average of 0.8°C for cooling by water and sand. This condition explains that the heat exchanger using either water or sand as medium cooling works well to lessen the temperature of the incoming water after being sprayed on the surface of the roof.

It shows as well the ability of the heat exchanger using water as cooling medium to cool the incoming water is more effective at the time of the morning from 8:00 to 11:00, while using sand as cooling medium more effective occur from 11:00 to 15:00. The average reduction in temperature between the water in and out of 0.83 with a standard deviation of 1.2. If the cooling medium in the heat exchanger was replaced with sand, it will be found an average reduction in water temperature is almost the same as that before the 0.81 with SD 0.89. The tendency of cooling is effective in the morning until noon.

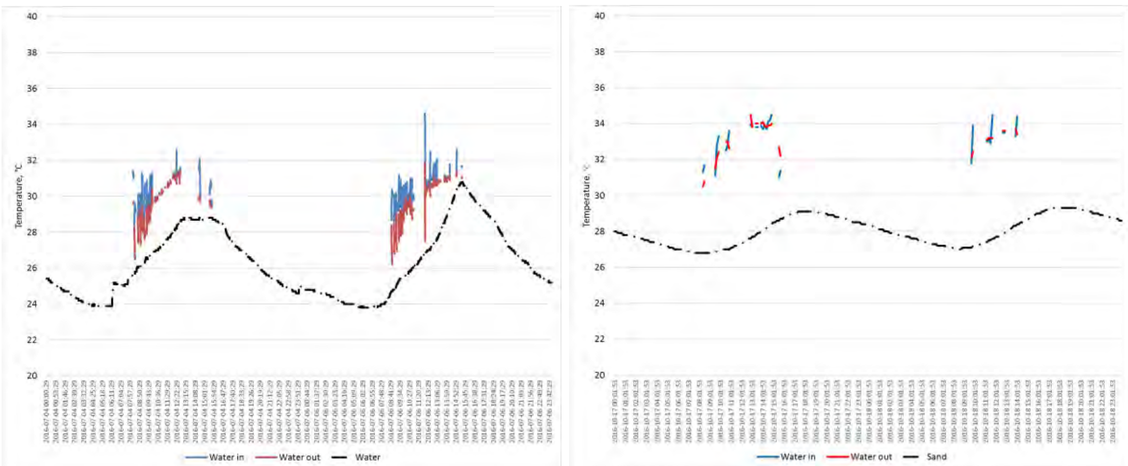

Figure 5. Roof surface, indoor and water-in and -out temperatures.

We assume the thickness of copper pipe is very thin. It signifies that the temperatures inside the copper pipe are the same with the outside and they are equal to the temperature of water. Based on the average temperature of 0.8° C and the effective length of copper pipe of 6.5 m, the mass flow rate and the rate of heat flow can be calculated by the forced convection in tube principles. The estimated values of them approximately are 1.106 kg/h and 515 Watts respectively.

Conclusion

Comparison of the performance of the heat exchanger using either water or sand has been carried out. Heat exchangers are used to cool water that has been sprayed onto the roof surface in the test cell using the automatic water spraying device. This device can work well to run water pump to spray the surface of the roof when it reaches 38°C or more. The water spraying onto the roof surface uses significant amounts of water, for that the attempts to reuse the sprayed water is the focus of this paper. Spray water flowed into the heat exchanger where the cooling medium using water or sand, their cooling performance was measured and compared.

The role of heat exchangers can lower the temperature of the water from spraying the surface of the ceiling, which has become a hot, down an average of 0.8° C using either water or sand. The ability of the heat exchanger using water as cooling medium to cool the incoming water is more effective in the morning, while using sand as cooling medium more effective occur at noon and afternoon. This exemplifies the benefits derived when using either water or sand as a heat exchanger as the cooling medium. The further work is to investigate from a mathematical model of the performance of the heat exchanger when comparing the different cooling medium. This design can be employed as a means to lower the temperature within the edifice in a humid tropical climate.

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The Influence of façade design on the optimum window to wall ratio and overheating rate in UK Passivhaus dwellings for current and future climates: A Parametric Design Method

Yahya Lavafpour and Steve Sharples

School of Architecture, University of Liverpool, Liverpool L69 7ZN, United Kingdom

Abstract: Many researches of overheating in buildings have focused on the optimisation of the window to wall ratio (WWR). However, the physical form of the building envelope has not been widely considered as a factor in optimisation investigations. This study examines if the optimum WWR might vary in response to slight geometrical changes to a façade's design. An evolutionary parametric design method was used to generate a range of inverted pyramidal shaped envelopes with different inclination angles for each façade. This was implemented for an existing UK Passivhaus. The WWR was set as the main variable along with a sub variable of different weather data (both current and future climate scenarios). This paper, in particular, focused on minimising the overheating during the summer while reducing the primary energy use of the building. These two parameters were set as the objectives to be optimised using the parametric tool in the dynamic thermal simulation software DesignBuilder. The calculation used batches of Energy Plus simulations using a genetic algorithm. The results showed that the optimised WWR varied significantly when implementing different façade arrangements. Optimum self-shading shapes could allow more glazing to be used while still achieving thermal comfort in summer climate.

Keywords: overheating, WWR, self-shading, warming summer

Introduction

In the mid-20th century the core principle of modernist architecture was that the shape of a building should be primarily based on its function – hence the phrase *"Form Follows Function"*, which was coined by the American architect Louis Sullivan. At that time, a building's intended use and its function were the most important criteria in designing the form of a building. The integration of the form and its relationship to a building's energy consumption means that the whole issue of a building's use needs to be considered differently in a sustainable context (Cody, 2006). A new architectural language introduced by Cody (2010) emphasised that the design of the building envelope was one of the key drivers for achieving energy efficiency in the built environment ('*Form Follows Energy*'). He argued how energy will become a new design parameter for future architecture. Research has demonstrated that buildings with different external envelope areas but similar internal floor areas can have different energy demands (Zerefosa, et al., 2012; Capeluto, 2003; Loonen, et al., 2013). Zerefosa et al, (2012) believed that the energy consumption of two buildings with the same materiality, volume, wall area, openings and operating programmes, displayed difference only due to the shape of their external envelopes. They examined the energy behaviour of a case study in Athens with polygonal and prismatic envelope shapes. The research pointed out that the prismatic formed building had lower solar gain compared to its orthogonal counterpart and consumed less energy in an annual cycle. (Gupta & Gregg, 2012; Laouadi, 2010) showed that shadings was the most effective single intervention for reducing overheating in homes for the future UK warming climate. Monitoring results from the Camden Passivhaus in London showed that summer overheating occurred between 15.00-19.00, with the maximum at 17.00 (Ridley, et al., 2013), suggesting that the overheating happened perhaps due to unnecessary solar gain.

Large south facing windows are common in Passivhaus designs as they provide free solar heating and daylight utilisation. Research has underlined that the optimum window to wall ratio (WWR) is around 25% for the Passivhaus standard. However, some Passivhaus buildings employ up to 60% south facing WWR (SF-WWR). This has raised the concern that the large areas of glazing would lead to increased discomfort hours under UK future climates, especially in London. By contrast, other façades have a very small percentage of windows, and there often is no windows on east or west Passivhaus elevations. Although this will alleviate unwanted solar gain, it will also potentially reduce cross ventilation, daylighting and view. Many researches have focused on the optimisation of WWR, while the form of the building envelope has not been included in the optimisation process. This study aims to investigate if the optimum WWR would vary as a result of slight amendments to the geometry of a façade's design. In particular, this study examined the concept of self-shading geometries.

Building shape and solar exposure

The greatest source of internal heat gain is usually from solar radiation, which enters the building directly through windows. In addition to various commonly used shading approaches, inclined facades have also been implemented to create a self-shadow on the building's glazing and envelope. The incidence angle between the direct solar beam and the building's surface changes as a result of changing the orientation of the building or the inclination of a façade, resulting in different values of solar gain. With no obstacle and shading factor, solar heat gains ($\Phi_{\mathrm{sol}}^{check}$) on a flat surface with a given tilt angle and orientation can be calculated using Equation 1:

$$\Phi_{sol}^{check} = \bar{\alpha}_s AT[I_d \rho(1 - cos \sum) + I_d(1 + cos \sum) + \frac{1}{\pi} I_b(cos \sum cos\, L^s + cos\, \psi\, sin \sum cos\, L^s + \sqrt{Sin^2 \psi Sin^2 \sum + (cos \sum cos\, L^s + cos\, \psi\, sin \sum cos\, L^s)^2})]$$

Equation 1

where A (m^2) is the area of the flat surface, $\mathrm{I_b}$ and $\mathrm{I_d}$ are the direct and diffuse solar irradiation (W/m^2) respectively, $\sum$ is the tilt angle of the surface, ψ is the orientation angle, ρ is the reflection coefficient from the ground, and $\mathrm{L^s}$ is the equivalent latitude, which depends on the specific month. This study used a computer-modelling tool, which makes it relatively straightforward to calculate and evaluate large numbers of design alternatives for solar gain.

Thermal discomfort

In the UK there is no universally agreed overheating criterion for residential building. This is perhaps because in the UK the retention of heating has been the main focus of thermal design and so overheating has not historically been a concern (Lomas & Porritt, 2017). The Housing Health and Safety Rating System from the Housing Act 2004 (Health and Safety Rating System , 2006) stated, "*a healthy indoor temperature is around 21°C. As temperatures rise, thermal stress increases, initially triggering the body's defence mechanisms such as sweating. High temperatures can increase cardiovascular strain and trauma, and where temperatures exceed*

25°C, mortality increases and there is an increase in strokes. Dehydration is a problem primarily for the elderly and the very young".

The Passivhaus standard requires that indoor air temperatures should not exceed 10% of occupied hours above 25°C for living spaces. CIBSE TM36 (2005) set the 'warm' and 'hot' temperature thresholds of 25°C and 28°C for living rooms and 21°C and 25°C for bedrooms respectively. CIBSE Guide A (2007) said operative temperatures should not exceed 10% of occupied hours above 25°C for living spaces (both living room and bedrooms). Operative temperature also should not exceed 1% of occupied hours above 28 and 26°C for living rooms and bedrooms.

Methodology

To generate a proposed self-shading form a parametric design method was used to generate a range of reversed pyramidal shape envelopes with different tilts on each façade. The form generation was carried out using evolutionary parametric tools Grasshopper and Galapagos (Rhino Plug-ins) to create an extensive range of façade inclinations to achieve a desirable fitness. A simplified box building (9m long x 7m wide x 3m high) was created as a base case for an initial pilot study. Eight points were formulated to create this box in different X, Y, and Z axes. The four points that created the base were kept fixed throughout the parametrisation analysis. The other four points (Figure 1), which were located at 3m high in the Z direction, were created using the number slider to manipulate the points parametrically. Each façade was divided into grids and the sum of the solar radiation received by each grid was calculated.

The Galapagos evolutionary computing tool was used to find the best fitness to minimise the solar radiation from 1 June to 30 August while choosing the optimised forms that received the higher solar radiation between 1 October and 30 March. Data analysis derived from the pilot study hypothesised inclination angles of 115° and 122° to be an effective shading intervention for the south and west walls respectively. The east-facing wall had a more complex shape, where the inclination angle for point D was steeper (117°) than for point B (103°). For the north facade the wall leant inward slightly at 87°. This geometry was then implemented in to the case study.

Implication to an existing Passivhaus case study

According to the Passivhaus Institute, the frequency of overheating increases sharply with a WWR of more than 20%. However, larger windows are often recommended (Schneider, 2006). The study used the design of an actual Passivhaus built by bere:architects called Larch House (Figure 2), which employed a SF-WWR of 55% (Bere, 2014). This house was modelled using the advanced dynamic simulation software DesignBuilder. Selected tilted walls from the pilot unit replaced the original vertical walls of the Larch House case study. Dynamic thermal simulations were used to examine the impact of these inclinations for the Passivhaus dwelling to make use of the self-shading that this form created. A sensitivity analysis of internal temperatures and thermal comfort conditions in the dwelling as a function of building facade inclination and prevailing climatic conditions was undertaken. The simulations were calculated for the living room and main bedroom. Windows assigned to the living room and the main bedroom on relevant facades were subject to the parametric analysis of WWR. This paper focused on minimising the thermal discomfort overheating during the summer while reducing the primary energy use of the building. These two parameters were set as the main objectives to see if the optimum WWR would vary by manipulating the façade geometry. The Optimisation Tool in DesignBuilder v5 was used to identify the optimum combination.

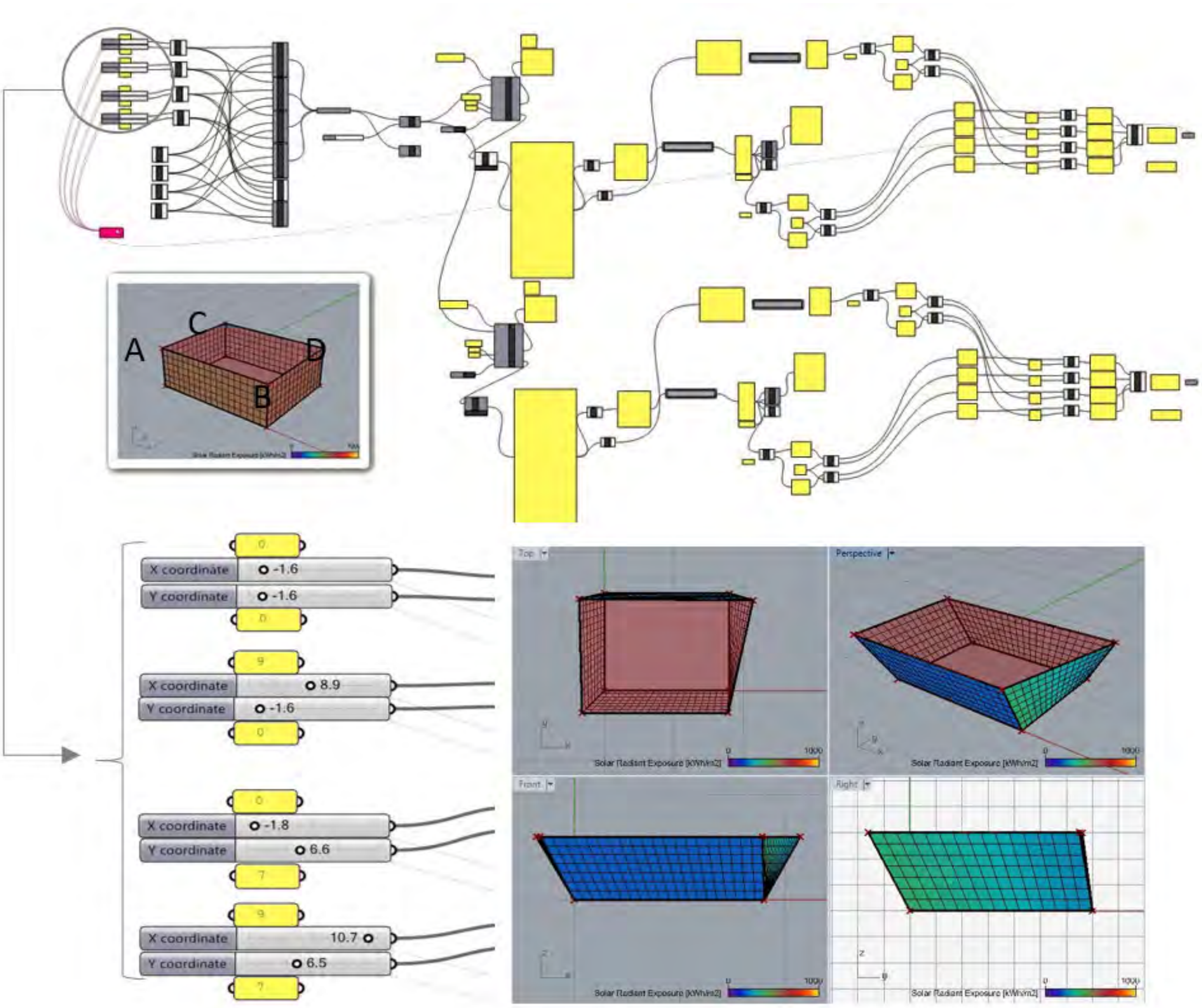


Figure 1. A snapshot of the parametric analysis (pilot unit)

Figure 2. Existing Larch House (bere:architects) and 3D model of the case study and modified geometry.

Weather data

This study used probabilistic climate change scenarios from the UK Climate Change Projections to determine the overheating risk in an existing Passivhaus dwelling under a high emission 50-percentile scenario in London. The PROMETHEUS team (Eames, et al., 2011) have developed future weather files in EnergyPlus format (.epw) using a UKCP09 weather generator. These hourly weather data files are available under low, medium and high emission scenarios with different percentile probabilities for both Test Reference Year (TRY) and Design Summer Year (DSY) weather data. They are available for three future intervals i.e. 2030's, 2050's and 2080's. DSY tend to give warmer summer days while TRY is more representative of the whole year. For the modelling in this study a high emission 50 percentile probability (A1F1 50%) was chosen. Since this study considered a whole year's energy performance it was felt that the Test Reference Year (TRY) data would be more representative of the year. London (Islington) weather files were used in the simulations as London is projected to experience the greatest temperature rise due to climate change and the impacts of the urban heat island (GLA, 2006).

Overheating criteria

There are two ways of assessing summertime thermal comfort – static and adaptive. This paper used CIBSE guide A (2007) static criteria, defined as overheating when indoor living spaces hit the 'warm' benchmark of 25°C for more than 10% of the occupied time and exceeds the 'hot' threshold of 28°C in the living room and 26°C in the bedroom for more than 1% of the annual occupied hours. Assessing thermal comfort based on the static criteria allows a focus on one specific parameter i.e. in this case the geometrical implication of the house. However, in reality, individuals will also adapt their behaviour to changing temperatures.

Results and Discussion

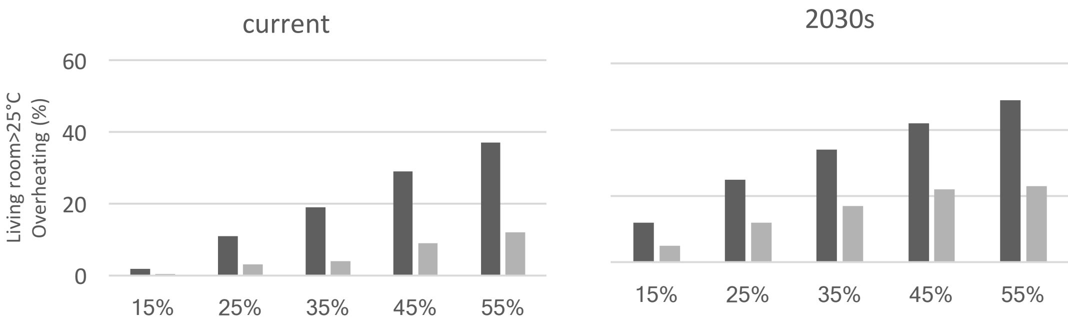
Table 1 shows a breakdown of the simulations, indicating the total hours that operative temperatures exceeded the static CIBSE Guide A threshold. This study used a generic UK household occupancy schedule. The bedroom was occupied (with different fractions) from 22.00 to 08.00 weekdays and from 23.00 to 09.00 at weekends. The living room was occupied from 17.00 to 23.00 weekdays and 09.00 to 23.00 weekends. In the current London climate, a similar house to the Larch House case study would experience warm indoor temperature (Lavafpour and Sharples, 2015). Considering the 55% WWR, the house with the original form in London current climate experienced 35% of the occupied hours equal or over 25°C ($h_{\vartheta} \geq 25$°C) in the living room, and 30% in the bedroom. Overheating in the living room was reduced to 12% using the optimised self-shading geometry. Tilting the façade on the south elevation, and the prismatic shape of the east façade, eliminated the 28°C/26°C overheating threshold but slightly exceeded the 25°C threshold limit. However, by reducing 5% of the WWR (i.e. down to 50%) the proposed geometry eliminated overheating in both rooms. Because of changing the façade angle, the average operative temperature dropped for both summer and winter periods. There was a slight increase in heating load for the optimum shape, which is greater in the current climate. Despite this increase, heating demand always remained within the Passivhaus limitation of 15 kWh/m^2 while assuring the minimum indoor temperature of 20°C.

The optimum shape building with 55% of glazing has almost the same Indoor operative temperature as the original shape with 25% WWR. The overheating percentage for the future climate also had a similar trend. A larger WWR on the optimum shape had an equal overheating risk than the original building shape with smaller WWR (Figure 3). The gap between the curves indicating overheating rate for different façade forms grows when the WWR exceeded 35% (Figure 4). The impact of the self-shading geometry is more apparent in the future weather scenarios. It can be seen that the original shape with more than 35% glazing area will experience a high risk of overheating even in the current climate. The optimum shape with 40%WWR had an acceptable overheating rate until 2050s weather projections; however, the proposed geometry could not eliminate overheating.

Table 1. Impact of form on WWR and the annual warm threshold hours for London current and future weather

WWR		Current		2030s		2050s		2080s	
		Original shape	Optimum * shape	Original shape	Optimum shape	Original shape	Optimum shape	Original shape	Optimum shape
15%	Living room≥25°C	80 hrs	21 hrs	543 hrs	242 hrs	823 hrs	406 hrs	1490 hrs	1010 hrs
	Living room≥28°C	0	0	0	0	24 hrs	11 hrs	128 hrs	19 hrs
	Bedroom≥25°C	22 hrs	0	314 hrs	90 hrs	482 hrs	176 hrs	857 hrs	559 hrs
	Bedroom≥26°C	0	0	67 hrs	3 hrs	151 hrs	27 hrs	460 hrs	185 hrs
25%	Living room≥25°C	484 hrs	116 hrs	1124 hrs	532 hrs	1379 hrs	788 hrs	2197 hrs	1449 hrs
	Living room≥28°C	0	0	108 hrs	9 hrs	232 hrs	40 hrs	832 hrs	251 hrs
	Bedroom≥25°C	259 hrs	21 hrs	676 hrs	267 hrs	876 hrs	408 hrs	1317 hrs	805 hrs
	Bedroom≥26°C	40 hrs	0	318 hrs	58 hrs	486 hrs	135 hrs	927 hrs	424 hrs
35%	Living room≥25°C	875 hrs	202 hrs	1531 hrs	752 hrs	1707 hrs	1002 hrs	2296 hrs	1596 hrs
	Living room≥28°C	36 hrs	0	253 hrs	54 hrs	470 hrs	111 hrs	1079 hrs	420 hrs
	Bedroom≥25°C	531 hrs	53 hrs	931 hrs	347 hrs	1066 hrs	519 hrs	1402 hrs	902 hrs
	Bedroom≥26°C	178 hrs	2 hrs	530 hrs	112 hrs	706 hrs	203 hrs	1048 hrs	524 hrs
45%	Living room≥25°C	1327 hrs	411 hrs	1903 hrs	1023 hrs	2046 hrs	1205 hrs	2522 hrs	1710 hrs
	Living room≥28°C	153 hrs	2 hrs	622 hrs	116 hrs	836 hrs	224 hrs	1420 hrs	599 hrs
	Bedroom≥25°C	839 hrs	491 hrs	1198 hrs	531 hrs	1281 hrs	717 hrs	1576 hrs	1048 hrs
	Bedroom≥26°C	459 hrs	207 hrs	834 hrs	231 hrs	952 hrs	379 hrs	1238 hrs	707 hrs
55%	Living room≥25°C	1578 hrs	525 hrs	2231 hrs	1051 hrs	2376 hrs	1240 hrs	2772 hrs	1766 hrs
	Living room≥28°C	433 hrs	0	1020 hrs	132 hrs	1212 hrs	224 hrs	1688 hrs	614 hrs
	Bedroom≥25°C	1059 hrs	515 hrs	1390 hrs	679 hrs	1439 hrs	846 hrs	1737 hrs	1158 hrs
	Bedroom≥26°C	694 hrs	269 hrs	1051 hrs	334 hrs	1136 hrs	495 hrs	1399 hrs	826 hrs

*Geometry obtained by this study (not global optimum)



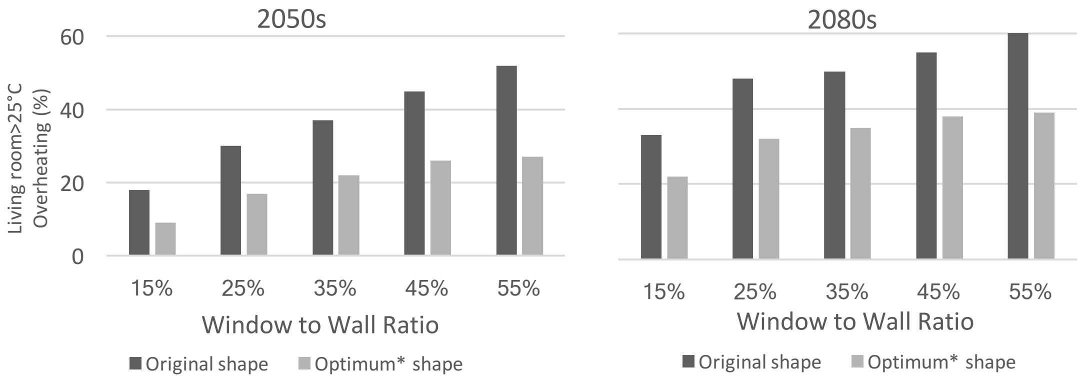
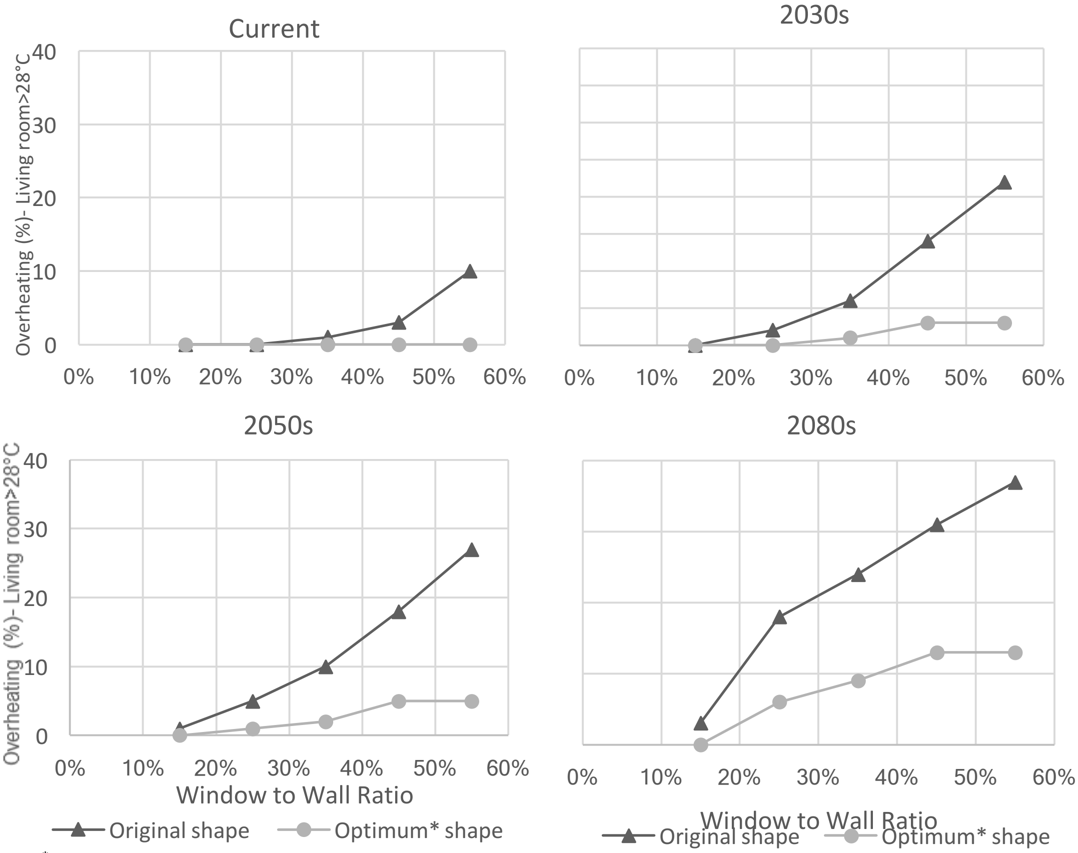


Figure 3. Percentage overheating time and WWR for current and future climates - 'warm' threshold overheating rate in living room



*Geometry obtained by this study (not global optimum)

Figure 4. Percentage overheating time and WWR for current and future climates - 'hot' threshold overheating rate in living room

Conclusion and future work

Optimal form of a building can significantly reduce direct solar gain without reducing the total solar heat gain needed for mild and cold regions, in particular for buildings with large glazing areas. The results from this study showed that the WWR varied significantly when implementing different façade arrangements. Self-shading facades allowed a greater window to wall ratio on the south and east facades and a steeper inclined wall for the west façade of the case study house, which originally did not have any windows, allowed for a small area of windows and potentially could increase cross ventilation cooling during the summer. The study was not trying to generate a complete optimal building form and cannot define finite performance criteria. However, the extent of a small design changes can be estimated using the result of the paper.

The shape of the external building envelope will also affect the daylight and airflow patterns. Future work will investigate the consequences that the proposed geometry may have on natural ventilation and daylighting.

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Thermal mass analysis of geometrically modified concrete ceiling using computational fluid dynamics

Daniel Sang-Hoon Lee[1]

[1] High-Performance Simulation Laboratory, Institute of Architecture and Technology, School of Architecture, The Royal Danish Academy of Fine Arts, Schools of Architecture, Design and Conservation, Daniel.Lee@kadk.dk;

Abstract: Often thermal mass applications of concrete floor/ceiling for indoor comfort have seen active developments around load shifting control strategies, in conjunction with direct/indirect thermal storage systems using hollow core concrete slabs. The main agenda was to increase the temperature difference between the cooled ceiling and the surrounding air for greater energy absorption by the thermal mass. In addition, there are recent developments in application of phase change materials (PCM), for increasing specific heat capacity of concrete. Meanwhile, a different direction of investigation can develop towards searching for geometrical forms of exposed ceiling, which may enhance the airflow for more efficient heat transfer between the air and the ceiling.
At centre of the current research is geometrical design of structural elements, which will guide the indoor airflow to increase the heat transfer efficiency. Thus the research addresses not only the heat transfer related design parameters, which include convective heat transfer coefficients, total surface area in contact as well as the temperature difference between the materials, but also the characteristics of indoor airflow. There, in application of computational fluid dynamics (CFD), the efficiencies of heat exchange through the concrete ceiling with specific geometrical profiles have been examined.
The current investigation adopted the authors' office space as a basic study model; however, the model includes more generalised space layouts including the furniture. The environmental scene was set to a peak summer day in Copenhagen, Denmark. The CFD simulations compare between more conventional flat, arched and ribbed ceilings and the comparison of the results between the ceilings were made based on the resultant indoor temperatures.

Keywords: Thermal mass, Concrete, Indoor Environment, Computational Fluid Dynamics, Geometry

Introduction

Energy efficiency of buildings are often measured in respect of the consumed embodied energy. Embodied energy in building analysis can be commonly discussed in two parts. Firstly, it is the initial embodied energy, which is related to the calculated energy consumption for the actual construction of the building. Secondly, it is the operational embodied energy, which refers to the energy consumption for the building's service period for heating, cooling, ventilation etc. In response to the global agenda to reduce the amount of carbon emission in construction industry, researchers have investigated to reduce embodied energy in both initial and operational parts.

The increasing number of researchers in structural and construction engineering fields have been investigating to optimise building structures for reduced initial embodied energy.

The optimisations are commonly achieved through innovations in high-strength low-density materials and the structural forms with the aim to design and construction of structures with the least amount material with extended life span and minimised maintenance. In regard of the operational embodied energy, there have seen active developments with the goal to reduce the level of energy consumption for the operation of mechanical building services, and for more increased use of passive systems in innovative applications of renewable resources. However, the above expertise can be developed for more synergetic research, where the design and construction methods of building structures are further investigated for possible reductions in both the initial and operational embodied energy.

The global research interests in thermal mass applications for energy efficient building design have seen steady growth. The research in thermal mass applications have been very appealing to the global researchers, for the investigations develop the ways to utilise the built structures, which have the initial purpose to resist the loads, for energy storage that can also release back the stored energy when required. Based on the material's thermal mass characteristics and for the wide applications, there have been active research for concrete thermal mass. The main areas of research include the development of efficient night ventilation and load shifting control strategy (Blondeau, et al., 1997) (Kolokotroni & Aronis, 1999) (Braun, 2003) (Yang & Li, 2008) (Sun, et al., 2013), and direct and indirect thermal storage system with exposed soffit and hollow core airflow respectively (Barton, et al., 2002) (Barnard, 2006) (Corganti & Kindinis, 2007). However, most of the research have been in the realm of incorporating the existing structural systems and develop either more passive ventilation strategies or mechanical systems; with the aim to reduce the starting temperature of the building structure and elements in the beginning of the daily thermal loading cycle.

In addition to the above, there have been interests of how geometrical forms of building elements affect the indoor environments. For indoor thermal comfort, it is considered that the geometrical configurations of structural and non-structural exposed elements of indoor space would affect the thermal conditions through their effects on indoor airflow and surface-to-surface radiative heat transfer. Therefore, the currently presented investigation was taken as a part of research, which explores the relationship between geometrical forms of building elements and resultant indoor thermal conditions. However, such research must be followed by in-depth understanding in the characteristic convective heat transfer behaviour based on slow indoor air movement and the radiative energy exchange. Therefore, the investigation was carried out based on computational fluid dynamics simulations, which would provide numerical data of three-dimensional indoor airflow and energy transfer.

3D Computational Model

There are first three models, which were constructed and analysed to examine the effect of three ceiling geometrical profiles on indoor temperature. The three profiles are 1) Flat ceiling, 2) Ribbed ceiling and 3) Arched ceiling. In the paper of Lee and Naboni (Lee & Naboni, 2017), it was mentioned that, despite the increased surface area of the ribbed ceiling, the hindrance to the air movement caused inefficient heat exchange between the air and the ceiling. Thus, in the current investigation it is proposed to make a comparison study between geometrical ceiling in other conventional forms such as flat and arched ceiling. The simulation models are constructed based on the actual meeting area (Figure 1&2) in the Institute of Architecture and Technology, School of Architecture in Copenhagen.

Figure 1. the meeting area at the Institute of Architecture and Technology which is used for the simulation.

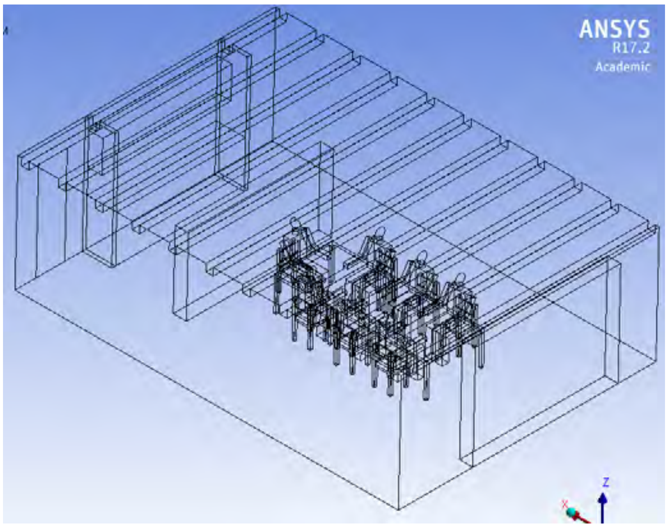

Figure 2. ANSYS Fluent 17.2 Simulation model (Ribbed ceiling) constructed based on the meeting area.

CFD Simulation Model and Set-up

The computational models were imported and meshed inside ANSYS. The furniture, partition walls and mannequins were modelled as individual volumes, which are placed inside an air domain, and all the elements were conformal meshed.

The assigned material properties of each volumetric units are defined in Table 1. It is to note that the material definitions for mannequin are actually ineffective for the simulations, as the boundary conditions were applied on the outer walls of the mannequin volumes. The material is created simply to give material definitions to the mannequins. All the volumetric elements were meshed with tetrahedron elements, which range from 2.0 to 4.0 cm in the sizes. In result, there are minimum 18.3 million finite elements for each simulation model.

Table 1. Material Definition

	Density (kg/m3)	Specific Heat (j/kg-k)	Thermal Conductivity (w/m-k)	Viscosity (kg/m-s)
Air	1.225	1006.43	0.0242	1.7894e-5
Wood (Furniture)	18	2310	0.173	-
Gypsum (Wall)	2320	1138	0.5	-
Concrete	2400	880	0.7	-
Mannequin (Human)	1062	3470	0.209	-

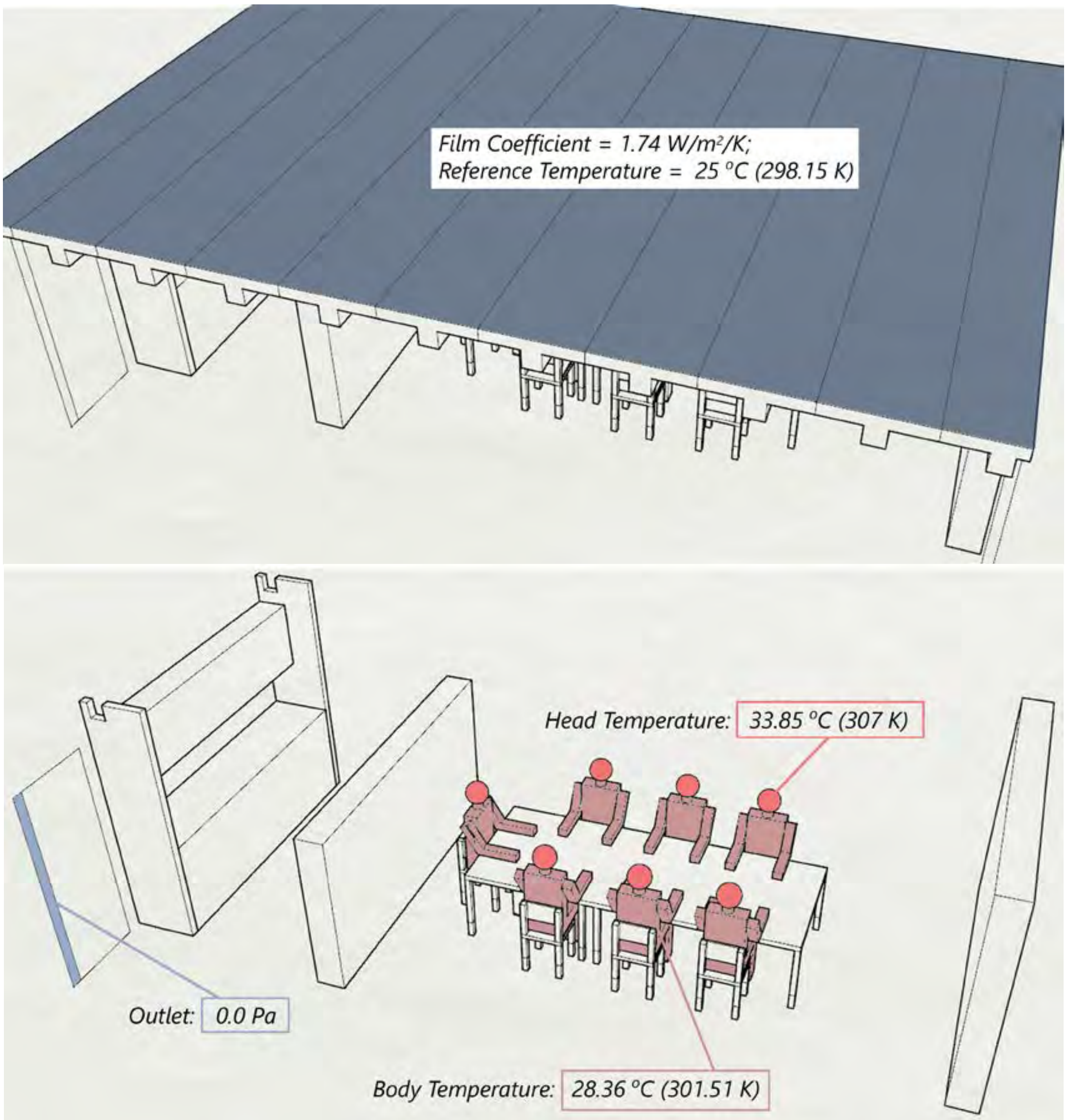

Figure 3. Assigned boundary conditions

The assigned boundary conditions for the simulations are described in Figure 3. The head and body temperatures of the mannequins are based on the measured mean temperature with summer clothing (Lee, et al., 2016). The heat transfer coefficient value was extracted from CIBSE Guide A; the transmittance U-value based on the construction description of 'vinyl floor covering, 50 mm screed 150 mm cast concrete'.

The steady state, pressure-based incompressible fluid CFD simulations were ran in ANASYS Fluent 17.2. The simulations adopted realisable k-ε turbulence model, and the energy transferred by radiation was considered using Surface-to-Surface (S2S) radiation model. All the simulations were ran equally for 500 iterations.

Results

The main interest in the current study is on whether different geometrical profiles for a fixed volume could give different indoor room temperature. Thus, the temperature data are extracted from results and compared between the cases of three ceiling profiles. The data extraction locations are described in Figure 4, and the average temperatures along the x-locations/m are plotted and compared for the three ceiling profiles in Figure 5.

As it can be seen from Figure 5, there is a clear pattern of the indoor temperature increasing when the ceiling geometrical profile varied from Flat to Ribbed. Please note that the high peak temperatures around 4.8 m location is for the data extraction points coincide with the mannequin's location. This result is in contrast with the statements by Lee and Naboni (Lee & Naboni, 2017), however, there could be a number of discussions around such contrast. As it can be seen in Figure 6, the ribbed ceiling has higher temperature distribution in comparison with the flat ceiling, and as described by Lee and Naboni (Lee & Naboni, 2017), the ribbed ceiling has higher efficiency of taking in the heat. However, the ribbed ceiling does not necessarily lose the heat more effectively than the flat ceiling, as the upper geometrical condition is the same. Thus, the stored heat remains in the ceiling and prevents any indoor heat to enter the concrete thermal mass. In result, as the current investigation is based on steady state solver, the indoor temperature rises until the system reached pre-defined energy balanced state, which gives higher indoor temperature than the case of flat ceiling. It would be more relevant to simulate based on transient solver, however, it would be greatly computer intensive to run for the current models with significantly large number of finite elements.

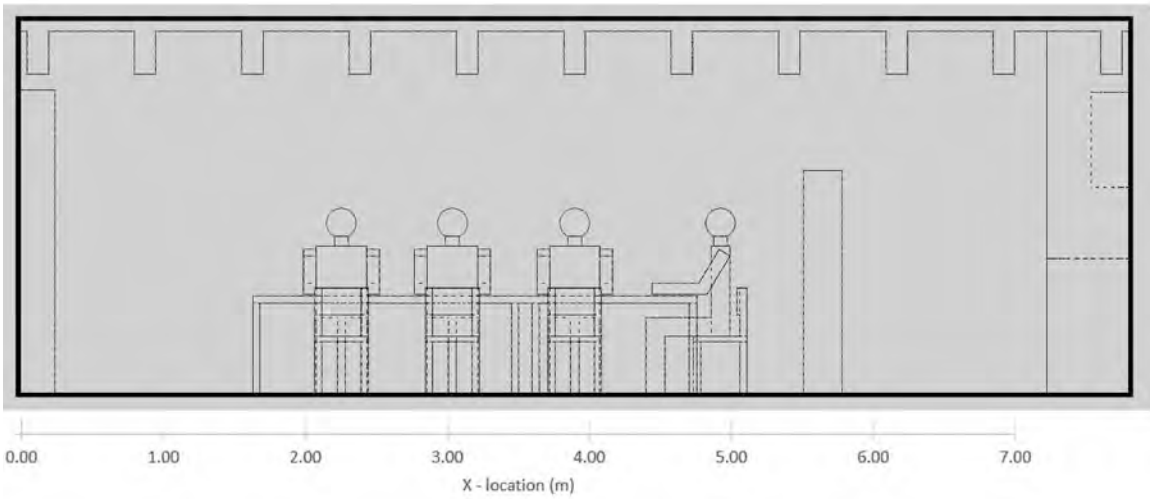

Figure 4. X-location for data extractions.

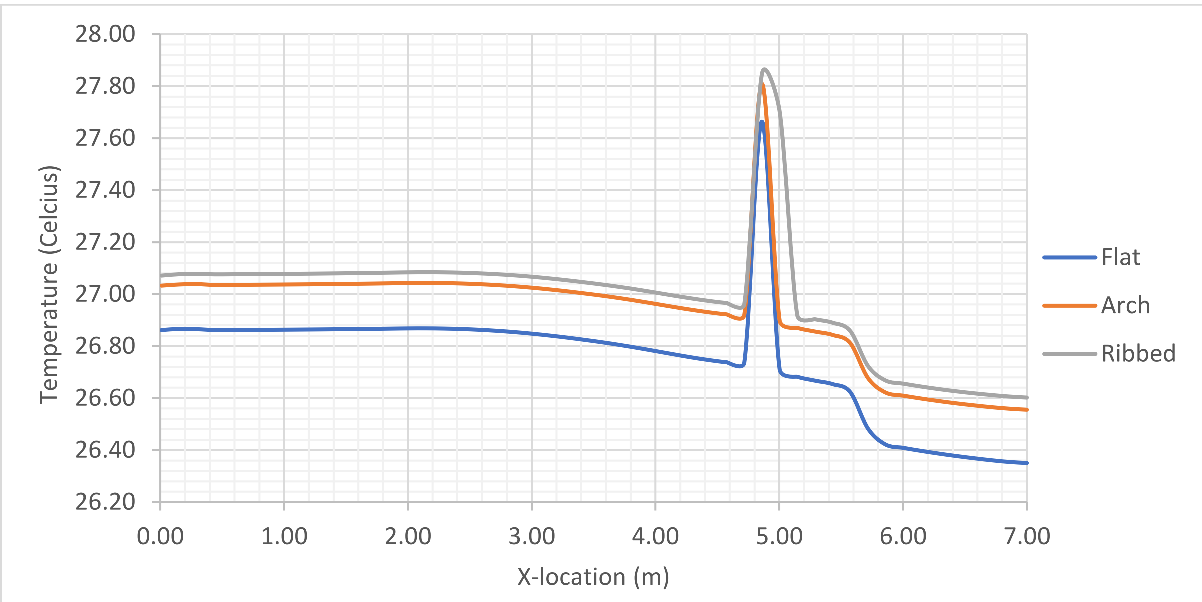

Figure 5. Comparison of average Indoor temperature for three ceiling geometrical types.

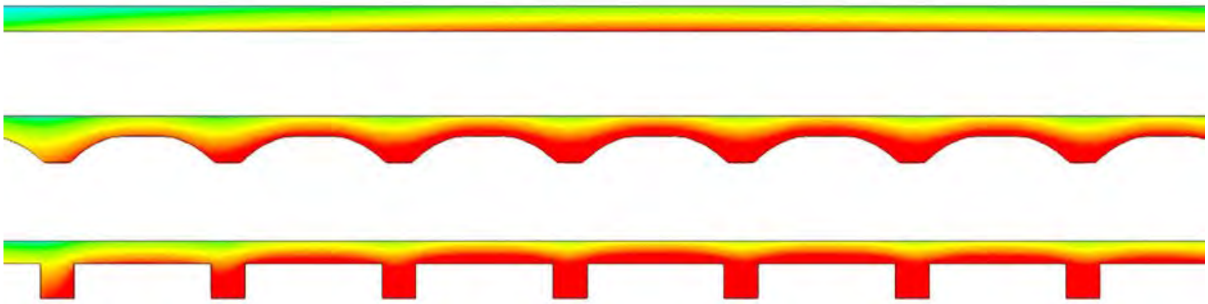

Figure 6. Comparison of temperature distribution inside Flat (Top), Arch (Middle) and Ribbed (Bottom) ceiling

Conclusions and Discussions

The current paper presented an investigation, which explored the relationship between the geometrical profiles of the exposed soffit and the ambient temperature. The investigation was carried out based on the numerical method using CFD, which was developed based on the site-specific context.

The simulation results showed that, based on steady state simulation the ribbed ceiling geometry resulted in highest indoor temperature. The mainly discussed reason for such result was that, the greater heat absorption efficiency of ribbed ceiling increased the overall ceiling temperature to higher level. This seems prevented further absorption of indoor heat, causing the indoor air temperature to rise. Thus, in order to design a concrete ceiling for efficient thermal mass performance, the geometrical optimisation must consider for both heat absorption and heat dissipation characteristics. Another obvious option would be to add more mass to the ceiling, for example, by increasing the depth of the web of ribbed ceiling.

In respect of the actual magnitude of the temperature rise, the impact of ceiling's geometry seems to have relatively minimal impact on the indoor temperature; even when the total mass of the arched and ribbed ceilings has increased in comparison with the flat ceiling. It is thought that such result is for the physical scale of the difference of three ceiling profiles are minimal in scale of the indoor space. It would be an interesting investigation to explore the effective scale of building elements, which would start to have significant influence on the indoor thermal environment. In addition, the possible transient simulation might provide better and more specific time-lapsed results.

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Natural Ventilation Systems in Texas Courthouses designed by James Riley Gordon: an Analysis of Development of Climate Responsive Typologies

Angela Lombardi[1], Simonetta Ciranna[2], Eleonora Laurini[2], Hazem Rashed-Ali[1], Patrizia Montuori[2], John Murphy, Jr. [1], Pierluigi De Berardinis[2], Michael Carroll[1]

[1] College of Architecture, Construction and Planning, University of Texas at San Antonio, San Antonio, Texas, USA;
[2] Department of Civil, Architectural and Environmental Engineering, Universita' degli Studi dell'Aquila, L'Aquila, Italy.

Abstract: The use of natural ventilation is an excellent strategy for achieving passive cooling in buildings, especially in hot and humid climate areas like in Southern Texas. The architect James Riely Gordon (1863-1937), after ten years of architecture practice, originated specific typologies of plans, extremely innovative in court house architecture to respond to South Texas climate, reinterpreting the period's attention in mechanical systems' innovations for ventilation and cooling and heating. Gordon designed seventeen courthouses in Texas, twelve of which are still existing and functioning at this time. From analysis of his work, we can identify a typological metamorphosis in the design development of courthouses, which evolved over time to become more technologically sophisticated and climatically efficient. This study investigates the design and construction features and climatic response strategies of these types of court houses, identifying the step by step evolution process in the development of these typologies, and specifically examines and assesses their natural ventilation effects. This step by step process developed by the architect for creating the best typological system intends to suit, simultaneously, style, function, technological innovations and mostly, environmental thermal comfort. These systems, now no longer in operation due to the adoption of mechanical ventilation systems, are rediscovered and reinterpreted as core elements of sustainable architecture, and could form valuable lessons for the contemporary sustainable design in hot humid climates.

Keywords: natural ventilation, hot-humid climate, Texas courthouses, signature plans, sustainable design

Introduction

Interest in passive design for either heating or cooling has re-emerged as a part of a movement towards sustainable architecture. Applying passive cooling means utilizing natural forces and design characteristics to achieve indoor thermal comfort, improve indoor air quality and make the building a better environment to live or work in.

This study shows how a climate-responsive approach, together with an interest on technological advancement, was one of the main foci in 19th century American architecture movement, as indicated by some architectural journals of that time. The architect James Riley Gordon (1863 -1937) in the design of Texas courthouses strongly contributes to the architectural debates of his time, when much effort and thought were devoted to the 'quest' an American style (Meister, 2011), associated to the adoption of modern technical and typological innovations, to create climate-responsive buildings. This paper also demonstrates, through the use pf performance simulation, how Gordon's courthouses can be considered effective climate-responsive structures, where comfort zone temperature is achieved during hottest periods of the year with the adoption of passive cooling strategies only.

James Riely Gordon (1863-1937) was San Antonio's most acclaimed architect during the final decade of the nineteenth century, despite his lack of formal education. The first major break in Gordon's career occurred in 1886, at the age of 23, when he was selected to supervise the construction of San Antonio's new federal courthouse and post office. Although his job description focused on project management and did not include design input, this project may have been the incubator for Gordon's interest to developing a courthouse design which effectively addressed the oppressive Texas heat by maximizing natural ventilation. Gordon brazenly suggested alterations to the building's orientation and room layout to the Supervising Architect of the United States Treasury, intending to make the building more responsive to the local climate, in particular to take advantage of San Antonio's prevailing south-easterly winds. The federal courthouse experience may also have cemented Gordon's affinity for the Richardsonian Romanesque style of architecture. Romanesque, with its fortress-like appearance of permanency, was a popular choice for civic architecture during the nineteenth-century's age of eclecticism. Gordon associates this architectural style to modern technical and typological innovations, as ventilation systems which inform the buildings' layout. Gordon was awarded his first courthouse commission in 1889, eight years after a legislative act allowing counties to finance their courthouses through bonds and taxes launched a building boom in county courthouse construction throughout Texas. Although the prolific architect's oeuvre includes extensive work in residential, commercial, and religious buildings, as well as the Texas Building at Chicago's Columbian Exposition, Gordon is best known as an architect of courthouses. In a note which appears to have been written around 1930, Gordon claims to have "nearly seventy successful court houses to my credit" (Gordon, ca. 1890-1937).

Technology versus Typology: Heating and cooling systems in the second half of 19th century and the development of climate-responsive typologies

Heating and cooling systems in the second half of nineteenth century: the debate in architectural journals

The mid-19th century witnessed the implementation of studies and experimentations on air circulation and climatic control in indoor environments, in both public and private buildings. Such studies, initially developed in England (Richardson, 1837; Ritchie, 1862) found fertile ground for both scientific and entrepreneurial interests in United States, especially in those areas of the country where the climate affects the quality of life.

In winter 1866-87 engineer Lewis W. Leeds gave various lectures on ventilation at the Franklin Institute of Philadelphia (Leeds, 1868). In these lectures, like in his treatise published in 1871, the main focus was on hospital buildings, Leeds presented his studies also on public and residential buildings. In his treatise, an article on the Municipal Hall of Pittsburgh, Pennsylvania was republished, previously published in March 1869 in the Philadelphia monthly journal «The Architectural Review and American Builders' Journal». (Leeds, 1871) The journal was at that time directed by the architect Samuel Sloan (1815-1884), who had hired Leeds since 1868 as a Consulting Engineer of Ventilation and Heating, for a column named *Ventilation and Heating.*

Heating and ventilation studies shaping a building's plan layout found ample space in the journal directed by Sloane, whose objective was to educate and inform architects and professionals for forming an American identity in architecture, appropriating and surpassing European models (Ciranna, 2014). One of the main requirements was that these models had to adapt to different climatic needs and to the accelerated progress of technology.

James Riley Gordon's Texas courthouses: developing climate responsive typologies

In Gordon's technical correspondence, the architect specifically addresses the courthouse buildings' design challenges due to the Southern climate: "It is not difficult in the South to keep comfortably warm during the winter, but it is a monster problem to keep cool during the long hot summer" (Gordon, 1890-1937). He also describes behaviour and performances of ventilating shaft with tower, stating that 'acts upon the same principle as a fire place with good draft…. except this is larger', being able to 'draw thousands of cubic feet of air per minute', with the result of having "the most practical, simple, effective and inexpensive system of ventilation" (Gordon, 1890-1937, AAA).

In an affidavit the architect composed in 1895, Gordon also elucidates five distinct phases in the evolution of his climate-responsive approach to courthouse design (Meister, 2011). Gordon's first courthouse was built in Rockport, Texas (Aransas County, demolished). This masonry building featured a central ventilation shaft and tower. He then converted the shaft to an open court, complete with a fountain, for Fayette County. To this design Gordon added colonnades, taking advantage of large Roman arches for introducing breezes. The next chapter in Gordon's courthouse development was an anomaly, owing to the specific brief presented for Bexar County. The fifth phase of Gordon's courthouse represents what Meister calls the architect's "Signature Plan". (Meister, 2011)

Table 1. Steps characterizing the typological evolution of Gordon's Texas courthouses' design

	Plan layout	**Innovation/variation of the type**	**Location**	**Year**
1	Hollow plan	"ventilating shaft and tower combined in the center of the building of solid masonry,…. introducing colonnades.." (Gordon Affidavit, Meinster 2011)	Aransas County	1889
2	Hollow plan	"Open court in the center with fountain.... collonnades all around the side" (Gordon, *ibidem*)	Fayette County	1890
3	Hollow plan	Similar to Fayette, with "outside colonnades and changed the exterior of a plan" " (Gordon *ibidem*)	Victoria	1891
4	Hollow plan	Unification of " open court, tower and ventilating shaft and changed the exterior design" (Gordon *ibidem*)	Bexar County	1894
5	Signature plan	"arranging the stairway with two platforms between each story, in the combined tower, ventilating shaft and court, and arranged the entrance from corners, through colonades then into vestibules and a rotunda or colonade around the tower with a series of arches…."	Brazoria County Hopkins County Gonzales County San Patricio County Van Zandt County Ellis County Wise County Comal County Lee County Harrison County Callahan County	1894 1894 1894 1894 1894 1894 1895 1898 1898 1899 1900
6	Capitol Plan	Expansion of cruciform 'signature' plan	McLennan County	1900
7	Copiah Plan	Innovative plan to meet criteria of the Copiah County Courthouse building committee	Angelina County	1901

In Texas Gordon designed seventeen courthouses, twelve of which are still existing and functioning at this time. The typological metamorphosis in the design development of courthouses evolved over time to become more technologically sophisticated and climatically efficient. Table 1 shows the step by step evolution process of Gordon's Texas courthouse typologies.

In his patented cruciform plan ('signature plan'), Gordon incorporated the ventilating shaft with court, tower, and stairwell. In addition, Gordon placed entrances at each of the four corners, utilizing distinctive curved colonnades to capture the natural breezes. Historians and preservation scholars underline how this plan was devised to increase the building's ability to naturally regulate a comfortable environment (Juarez et al, 1996; Meister, 2011), as described by Salisbury: "as air strikes the building it gives off heat, forced through an opening it expands absorbing heat, and rising through a central atrium it gives off heat which then rises [and escapes] through the central tower".

Subsequent sections of this paper will use simulation tools to assess the effectiveness of some of these climate responsive buildings configurations focusing on the Fayette and Lee courthouses, which represent two main steps in Gordon's typology development process: the first featuring a hollow plan layout, and the second represents the 'signature plan' design of the last building Gordon designed in the Richardsonian Romanesque Style.

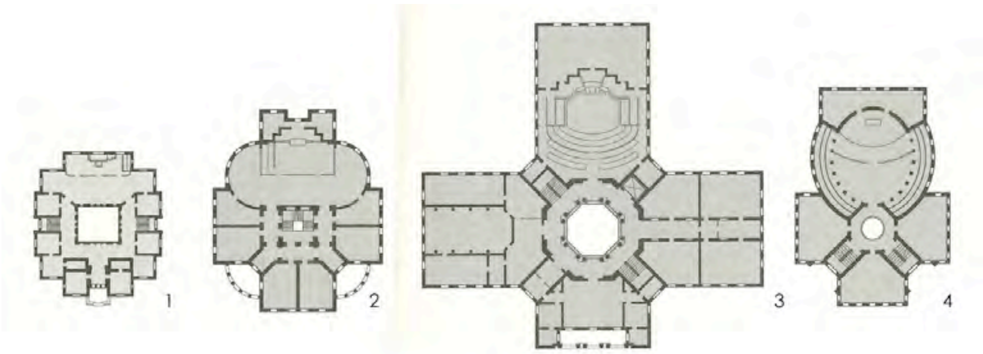

Figure 1. Overview of typological layouts adopted by James Riley Gordon: 1. Hollow plan; 2. Signature plan; 3. Capitol plan; 4. Copiah plan. (from Meister, 2011)

Figure 2 and 3. The Fayette courthouse, in La Grange, designed in 1890 and Lee County Courthouse, in the city of Giddings, designed in 1898

Climate responsive assessment in Fayette and Lee County Courthouses

Methodology

A qualitative assessment of air flows providing passive cooling effects is an essential tool for identifying the areas of the buildings most representative to study the performance of the structure in terms of passive cooling strategies. Following the preliminary qualitative analysis of the air flow patterns in the two buildings under analysis, this study utilizes CFD simulation as the main investigatory method. The CFD analysis utilized the software Design Builder. The modelling focused on the building core, where most ventilation flows took place. In order to compare the difference between the two buildings' performances in hot humid climate, San Antonio climate data was used as the bases for analysis in both situations. While there may be minor differences between the climates of the three cities: San Antonio, La Grange, and Giddings, all three fall in climate zone 2a of the international climate zone definitions, which is characterized by having between 6300 and 9000 CDD50◦F and an annual precipitation higher than 20" per year. This zone is typically dominated by cooling needs. The CFD simulations took into consideration both the incoming ventilation from the outdoor environment, based on the local climatic data, as well as air flow through indoor openings.

The Fayette Courthouse analysis and simulation

Building description: Gordon employed a hollow square floor plan, subdivided in five bays and characterized by a 30' x 30' spacious atrium or courtyard, with arrangement of offices and courtroom around it, with arched entrances located at the center of each side. Stairwells are located above these arched entrances starting from the second story. The load-bearing masonry walls for the exterior are made of four different types of native Texas stone.

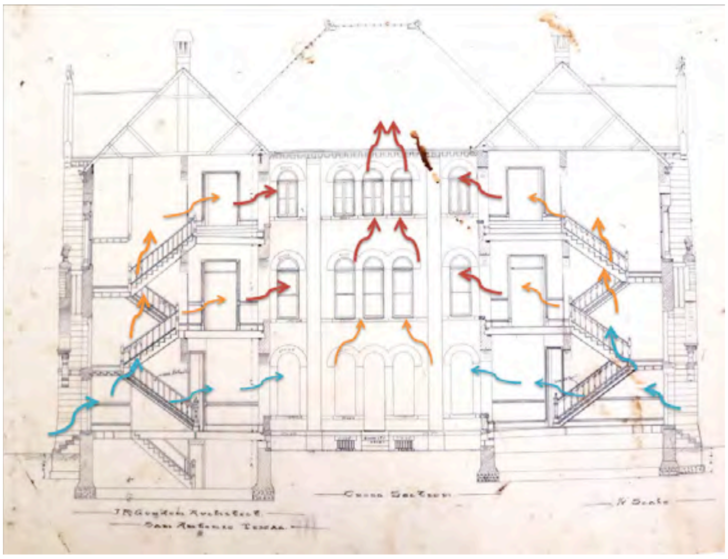

Figure 4: Section of the building showing air flows.
Blue: cool air; Orange: warm air; Red: Hot air

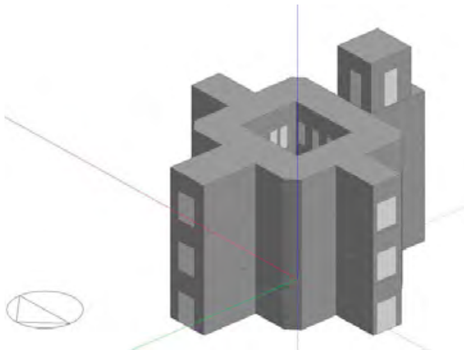

Figure 5 and 6: 3D modelling and axonometric section developed with software Design Builder

Air flow patterns: Air flow through the two stairwells from doors and windows located on the building's exterior facades, and, getting warmer, they rise through the vertical circulation spaces. Subsequently they are driven into the internal court, increasing convective air currents due to thermal gradients of air stratification and increasing the exhaust of warm air inside the circulation spaces which generates a pressure differential due to the vertical movement of warm air. The fountain, located by the architect in the center of the courtyard, has an important bioclimatic function as they can cool the air through evaporative cooling. The fountain therefore acts as air flow cooling point, contributing to improve comfort conditions in the spaces surrounding the courtyard. The CFD simulations conducted in this work do not take into account the presence of the fountain, therefore the below data may overestimate air temperature.

The Lee Courthouse analysis and simulation

Building description: The Lee County Courthouse, completed in 1899, is one of the last of Gordon's Texas Courthouses and is the last building he designed in the Richardsonian Romanesque Style. The building is an example of the architect's patented cruciform plan, 'ventilating shaft with tower', with integrated stairwell which serves the various building levels. It features rounded porticos between each wing of the building where entrances are located, bringing the visitor diagonally into a central stair hall, culminating in a clock tower, with openings on the four sides. (Henry, 1993).
Load bearing walls, with its high thermal mass, are made of red brick, contrasted, in the facade with white limestone trim.

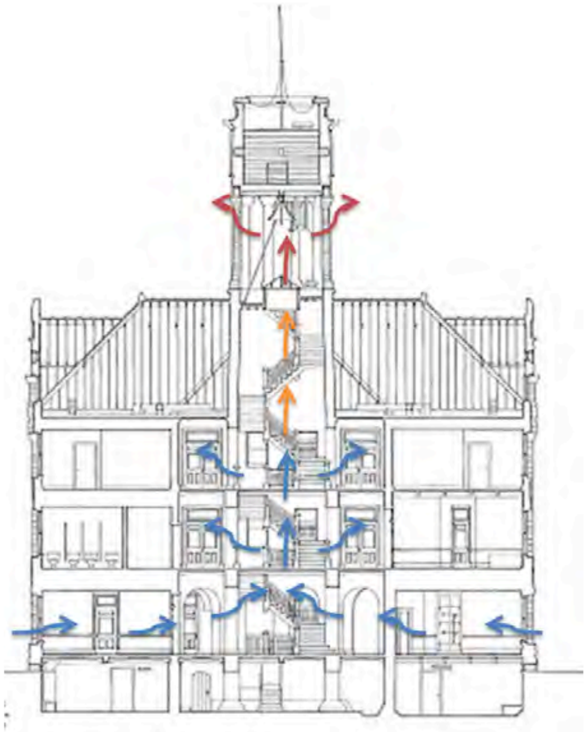

Figure 7: Building section with schematic air flows. Blue: cool air; Orange: warm air; Red: Hot air

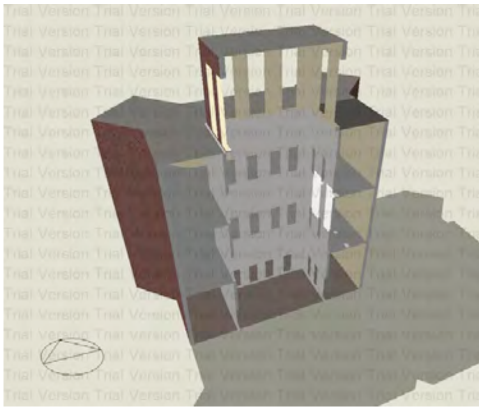

Figure 8: 3D axonometric section developed with software Design Builder

Air flows description: Air flows enter from the four entrances at the first floor, and it is channelled in the central ventilating shaft, increasing its temperature meanwhile rising. Airflows, in this way, are naturally expelled from the openings located on the top of the tower, which act as a ventilating chimney.

Simulation output

Table 2 shows average values of air temperature, radiant temperature and relative humidity obtained through the CFD simulation of both buildings. In case of the Fayette county courthouse, temperature data are high, while relative humidity is within the acceptable comfort parameters, demonstrating the thermal comfort performance of the building typology.

Table 2. Fayette and Lee Courthouses. Comparative simulation results showing Air Temperature, Radiant Temperature and Air Humidity.

	FAYETTE Courthouse Average Results during Summer Season (from May to September)			**LEE Courthouse Biweekly Average Results during Summer Season (from May to September)**		
Schedule	Air Temperature (°C)	Radiant Temperature (°C)	Air Humidity (%)	Air Temperature (°C)	Radiant Temperature (°C)	Air Humidity (%)
May 1-12	30.2	31.3	25.9	25.5	26.3	34.6
May 13-25	30.8	31.5	59.6	24.9	26.3	67.1
May 26- Jun 7	33.8	34.5	44.3	29.2	29.8	56.7
Jun 8 – 20	35.2	37.2	45.1	25.2	27.1	62.1
Jun 21- Jul 2	37.0	38.0	41.7	26.4	29.3	56.4
Jul 3-14	37.0	38.7	43.0	25.5	27.4	63.5
Jul 15- 26	36.4	37.7	42.4	25.9	28.1	58.5
Jul 26- Aug 6	37.5	38.5	41.2	29.0	29.1	67.3
Aug 7- 18	35.5	37.3	32.0	25.4	27.6	49.8
Aug 19 -30	37.4	38.4	45.8	31.0	31.2	66.7

Tables show biweekly average maximum values of temperature and humidity

In case of Lee county courthouse, temperatures are clearly lower, while relative humidity appears to be higher even if it is still considered within limits of the thermal comfort zone

Analysis of Results

The comparison of the two simulation results is undertaken through the insertion of the data shown in Table 1 and 2 in the psychometric comfort chart using online CBE Thermal Comfort Tool (CBE, 2017). The analysis was based on the following parameters: Air speed: 0.1 m/s (within acceptable parameters); Metabolic rate: 1 met (for sedentary activities, as suitable for courthouses); Clothing level: 0.1 clo (tropical clothing).

Table 3

	FAYETTE	LEE
Thermal sensation	**Hot**	**Neutral**
PPD (%) (Percentage of Person Dissatisfied)	100 %	7%
PMV (Predicted Mean Vote)	3.83	0.31

Figure 9. Psychometric chart showing CFD simulation results and comfort conditions.

As shown in figure 9, "input #1" data are related with Fayette courthouse, input #2 data are the ones for Lee Courthouse. In case of the Fayette Courthouse, the analysis shows that average comfort conditions fall well outside the comfort zone (in purple) mostly because of the high air temperatures. As discussed previously, the CFD analysis did not account for the potential impact of the fountain which will likely reduce this temperature resulting in the conditions being closer to the comfort zone. On the other hand, for the Lee Courthouse, the analysis shows the average conditions (in purple) to be within the acceptable range of thermal comfort. Therefore, we can conclude that the simulations shows the cruciform plan, patented by the architect, of the Lee Courthouse represents is more successful in achieving indoor thermal comfort conditions most likely due to the integrated ventilating shaft and tower, where the stairwell was also located.

Conclusions

This paper attempts to combine two methodological approaches to architectural research: historical analysis as carried out by preservationists and the use of performance simulation, to assess the work of a prominent architect: James Riley Gordon. Through historical analysis, the paper demonstrates that the architect consciously integrated climate-appropriate and responsive strategies into his court house designs in Texas. Mainly the use of natural cross and stack ventilation as well as evaporative cooling, and that he did so as a part of a wider movement in the US at the time. Through the use of CFD performance simulation, the paper assessed two major phases in the evolution of Gordon's courthouse designs from the point of view of their ability to achieve indoor thermal comfort conditions. The simulation showed that Gordon's signature plan, illustrated by the LEE County Courthouse, is more successful in achieving indoor thermal comfort conditions in the hottest time of the year than the earlier design, illustrated by the Fayette County Courthouse. This is consistent with the evolution of the architect's work and with his writings which contended that his signature plan represents an improvement with respect to passive design characteristics.

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Thermal behaviour of urban semi-open spaces in the Mediterranean climate: the case of shopping arcades in the historic centre of Nicosia, Cyprus

Eleni Malaktou[1] and Maria Philokyprou[2]

[1]Department of Architecture, University of Cyprus, meleni@ucy.ac.cy
[2]Department of Architecture, University of Cyprus, mphiloky@ucy.ac.cy

Abstract: Urban public or semi-public, semi-open spaces formed, over time, focal points for trade, exchange, social interaction and political discourse. Such spaces, which are neither indoor nor outdoor, reduce the comfort expectations of users who are tolerant to a wider range of environmental conditions compared to the users of indoor spaces. Considering that thermally comfortable public spaces are essential for the social vitality of the urban realm, semi-open typologies may be (re)considered as positive design elements in sustainable urban planning practices. This paper investigates a particular semi-open typology, namely the shopping arcade, in Nicosia historic centre. It focuses on both the arcades' thermal behaviour and on the links between architectural form and environmental performance. Initially, on-site documentation and collection of geolocation data was undertaken, followed by a classification of the architectural characteristics of arcades. More than fifty arcades were identified and a sample of sixteen representative examples was selected for seasonal thermal monitoring. The findings suggest that arcades are well performing passive urban environments. Their variable architectural forms can provide microclimatic diversity and thermal adaptation to human nature, which can result in more frequent use and prolonged occupancy of the urban domain.

Keywords: semi-open space, arcade, summer thermal monitoring, thermal behaviour, Mediterranean climate

Introduction

Public or semi-public, semi-open spaces link private and public domains and have served, throughout the years, transitional, social, economic or political purposes. These covered passages —bordering a square, lining a street or passing through an urban block— form attractive places for dynamic (e.g. walking) and/or static (e.g. standing, sitting) activities. Such space types enable a gradual thermal transition between interior and exterior space and demonstrate a particular knowledge on how to achieve control over the microclimate by passive means. Semi-open spaces do not depend upon artificial thermal control and thus increase the thermal acceptability limits of the users. The positive thermal effects and benefits of such designs are thoroughly researched in vernacular architecture (e.g. Andreou & Axarli, 2012; Malaktou, et al., 2016; Sinou, 2007; Rudofsky, 1964), while such effects are less documented in the industrial era (e.g. Potvin, 1997) and the 20th century architecture (e.g. Tsiros & Hoffman, 2014).

In recent years, the wide use and dependence on artificial heating and cooling, the interiorisation of public space, hectic lifestyles, the automobiles effect and the development of telecommunications which enable social interaction in a virtual instead of a physical space, have changed the nature of the built form and led to the decadence and limited application of the semi-open type. Rudofsky (1969), in his book *Architecture without* *architects*, points out the fast disappearance of such typologies in vernacular architecture while Brown et al. (1998) and Wilson-Doenges (2001) identify a decline in the use of semi-open spaces in domestic architecture. Nowadays, the imperative need to tackle climate change effects, to mitigate the Urban Heat Island related problems and to achieve energy conservation, force us to re-visit and re-assess the potentials of semi-open spaces within a larger urban design context that would benefit contemporary society. In addition, since social attendance and interaction in semi-open or open spaces has proven to be strongly influenced by microclimatic issues (Nakano & Tanabe, 2004; Gehl, 2001; Nikolopoulou & Lykoudis, 2007), semi-open spaces, which form authentic bioclimatic design elements, can be reconsidered as tools for strengthening sociability and restoring a sense of community in the public space.

The present paper analyses a particular semi-open space type in Nicosia historic centre in Cyprus, namely the shopping arcade. According to Geist (1989), a *shopping arcade is defined as a covered passageway which connects two busy streets and is lined on both sides with shops*. This type was selected over other semi-open typologies because of the numerous examples found in Nicosia, because of their neglect within the urban fabric, their significant social role and the relatively scarce scientific data found in the literature related to their architecture and their environmental behaviour. In the case of Nicosia historic centre, this particular type appeared in the beginning of the 20th century, when in other major European cities it had already fallen into decline and was gradually replaced by department stores (Geist, 1989). The development of the arcade is a result of westernisation, modernization and urbanization processes in the island during this period. Historically, this type was quite popular during the 1960s; a time which coincides with a high building density construction in Nicosia following the demolition of many traditional structures for new developments. The 1980s marked a decline of the retail arcade concept which put a stop to its implementation within the urban fabric.

This study —which is a part of a wider research on the socio-environmental aspects of shopping arcades— focuses (a) on the summer thermal behaviour of these spaces and further (b) on the interrelation between the arcade architectural form and thermal behaviour. The aim of this research is to illustrate the thermal benefits of arcades over the external environment, to reveal opportunities for thermal comfort enhancement in the urban context through the application of the arcade type on the neighbourhood/district level and to provide design guidelines for such spaces based on environmental criteria.

Methodology

A three-fold methodology was followed, including (a) on-site identification and documentation, (b) archival research and (c) on-site thermal monitoring, in order to provide a holistic approach in the understanding of the shopping arcades in question. Initially, on-site collection of geolocation data, as well as description and classification of the architectural characteristics and bioclimatic aspects of arcades, was undertaken using photos, maps, sketches and notes (Malaktou & Philokyprou, 2016). Supplementary material to the on-site data, such as information about the year of construction, the architects involved in their design and architectural drawings, was acquired through the Municipal and Governmental archives. More than fifty arcades were identified and a sample of sixteen representative examples, as well as one reference indoor space, were selected for continuous air temperature and relative humidity monitoring. Additional data of outdoor climatic conditions was obtained by a VantagePro weather station, located at downtown Nicosia. Arcades were surveyed seasonally between August 2016 and May 2017. The last part of the methodology, which concerns the summer thermal monitoring, is the focus of this paper. Summer measurements of air temperature and relative humidity were carried out between August 1st to 31st, 2016, using Hobo UX100-003 type sensors. The sensors were carefully placed in order to ensure protection against direct solar radiation. The analysis of results included the presentation of mean minimum, average and maximum temperatures and temperature fluctuations of arcades with respect to the corresponding values of the outdoor environment, in order to estimate their potential cooling effect. In addition, a statistical process, i.e. a regression analysis, was performed to evaluate the dependence of the cooling effect of arcades on weather conditions. Finally, another statistical analysis was performed to demonstrate how the Degree of Enclosure (DoE), as called by Sinou (2007), affects the thermal environment of semi-open arcades. The Degree of Enclosure is defined as the ratio of the sum of all closed and open surface areas (A_{total}) to the sum of the open surface areas (A_{open}) (Steemers , et al., 2004). The purpose of this analysis is to demonstrate to what extent a particular architectural form of a space affects the microclimate within it.

Case studies description

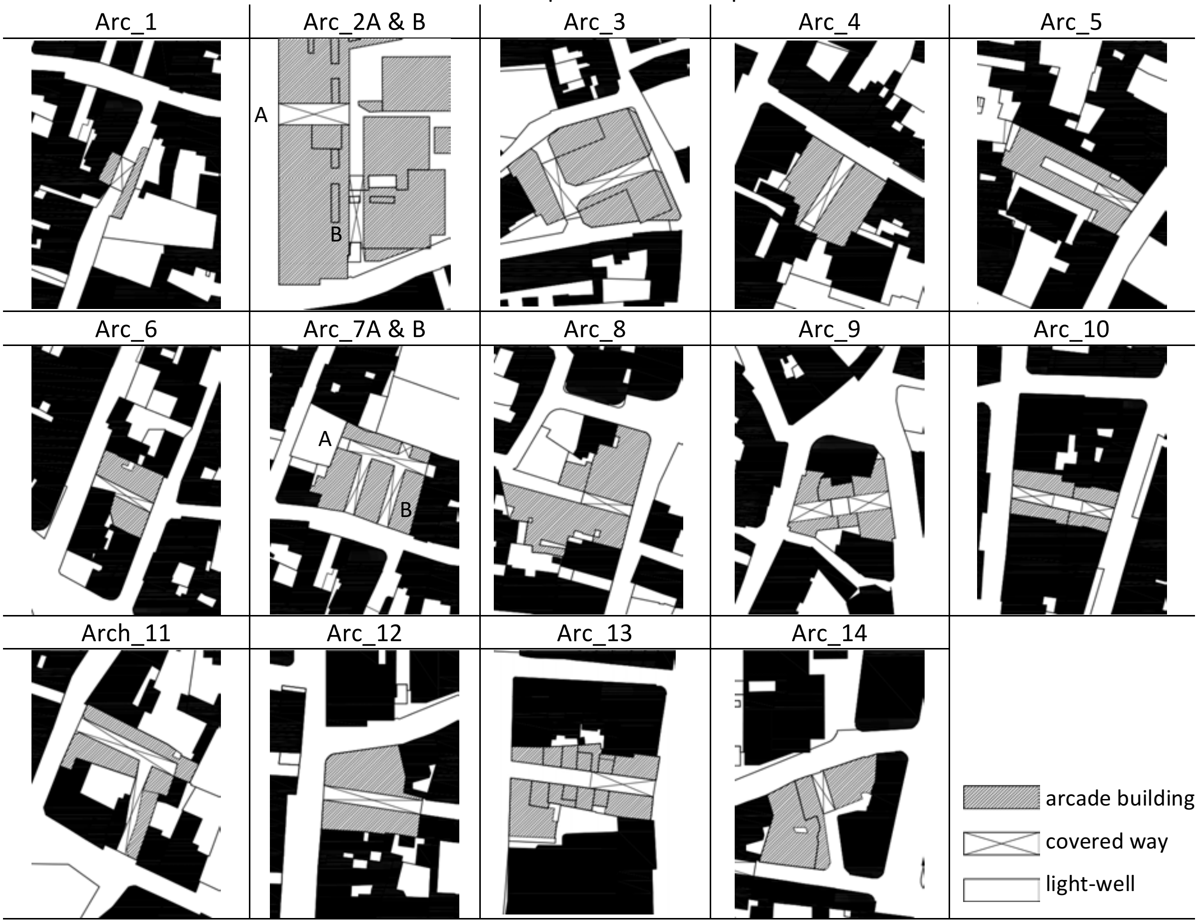
Detailed information on case study spaces is provided in Tables 1 and 2. The majority of arcades under examination feature a linear straight passage (I-shaped), a type that is most commonly found in Nicosia. Other more complex types, such as L-shaped and U-shaped configurations, although sparsely applied, are also included in the sample. Due to the compact planning of the Nicosia historic centre, many arcades are built on land-locked sites; a fact that restricts the possibility of a through passage. Such design examples, are identified in Arc_4 and Arc_5. The DoE of the sample varies between 5.5 and 25.5. Given that the major commercial thoroughfares are mainly developed along the North–South axis,

Table 1. Sample characteristics from on-site observation, maps and archives

	Orient.	Typology	Through Passage	DoE	Construction		
					Materials	Roof	Year
Arc_1	N–S	I-shaped	Yes	05.5	C[1]	F[3]	?
Arc_2A	E–W	I-shaped	Yes	10.0	C	V[4]	1970
Arc_2B	N–S	I-shaped	Yes	10.8	C	F/SL[5]	1970
Arc_3	SE–NW	L-shaped	Yes	08.1	C	F	1969
Arc_4	N	I-shaped	No	25.5	C	F	1956
Arc_5	SE–NW	I-shaped	No	09.8	C	F	1959
Arc_6	SE–NW	I-shaped	Yes	12.0	C	F	1956
Arc_7A	E–W	U-shaped	No	22.8	C	F/LW[6]	?
Arc_7B	S	U-shaped	No	22.1	C	F	?
Arc_8	E–W	I-shaped	Yes	09.3	C	F	1956
Arc_9	E–W	I-shaped	Yes	08.6	C	F/LW	1963
Arc_10	E–W	I-shaped	Yes	08.1	C + LS[2]	F/LW	1932
Arc_11	E	L-shaped	Yes	20.2	C	F/S	?
Arc_12	E–W	I-shaped	Yes	13.3	C + LS	S[7]/SL	1932
Arc_13	E–W	I-shaped	Yes	08.4	LS	F	Prior 1930
Arc_14	N–S	I-shaped	Yes	06.5	C + LS	F	Prior 1930

[1]C, concrete; [2] LS, local stone, [3]F, flat; [4]V, vaulted; [5] SL, skylight; [6]LW, light-well; [7]S, saddle

Table 2. Sample architectural plans



the majority of the sample is positioned along East–West axis. The arcades under examination, with the exception of Arc_12, are covered by high-mass roofs. High-mass roofs for this semi-open type are traditionally associated with low latitude countries, as opposed to high latitude countries where glazed roofs prevail.

Results and Discussion

Thermal behaviour assessment

The monitoring results of the entire summer experimental period indicate that, in principle, all arcades present remarkably lower mean maximum temperature values than the corresponding value of the outdoor environment (Table 3). More specifically, differences in mean maximum air temperature between the arcades and the outdoor environment vary from 1.0 to 3.9°C, while the peak reduction of maximum outdoor temperature reaches the 5.4°C (Arc_4). This cooling effect is attributed to the combined effect of compact urban morphology, orientation, shading and thermal mass. It is interesting to note that the maximum cooling effect for the majority of arcades under examination occurs during the hottest day of the monitoring period, i.e. 8/8/2016, when maximum outdoor temperature reaches 39.9°C. This indicates that maximum cooling effect in arcades is more associated with hotter days. To provide a better understanding of the cooling effect of arcades, a linear regression was performed between the outdoor daily maximum temperature, i.e. T_{max_out}, and the difference between the daily maximum temperature of the outdoor environment and that of arcades, i.e. $T_{max\_out} – T_{max\_arc}$ (Table 4). Table 4 shows a good degree of relationship in the patterns of variation between T_{max_out}

and $T_{max\_out} - T_{max\_arc}$ in the majority of case studies (R^2 = 0.46–0.81). This confirms that the outdoor air temperature has an impact on the level of cooling; i.e., the higher the maximum outdoor temperature, the stronger the cooling effect within the arcades. The values of the slopes are in a range of 0.16 and 0.49, indicating that maximum temperatures of arcades are always below the corresponding values of the outdoor environment. Applying the resulted regression, when outdoor maximum temperature rises by 5°C the cooling effect values of arcades are expected to be enhanced from 0.8 to 2.5°C. The above results are in line with the results of Tsiros & Hoffman (2014) carried out in the summer in semi-open spaces of Athens.

Table 3. Summary of recorded environmental data during hot, summer period

	Mean Values						Peak and Trough Values			
	T_{max}	T_{min}	T_{avg}	$T_{fluct.}$	T_{max_out} - T_{max_arc}	T_{min_out} - T_{min_arc}	T_{max}	T_{min}	T_{max_out} - T_{max_arc}	T_{min_out} - T_{min_arc}
Outdoor[1]	**37.0**	**24.4**	**29.6**	**12.6**			**39.9**	**22.7**		
Indoor[2]	**34.1**	**31.4**	**32.4**	**2.5**	**3.5**	**-6.7**	**34.9**	**30.1**	**1.0 – 5.6**	**-8.3 – -4.5**
Arc_1	34.2	27.4	30.1	6.8	2.8	-2.9	36.0	25.7	1.7 – 4.0	-3.6 – -2
Arc_2A	35.6	27.8	31.6	7.8	1.4	-3.4	37.6	25.7	0.3 – 2.4	-4.6 – -2.8
Arc_2B	35.8	28.1	31.5	7.7	1.2	-3.7	38.1	26.0	0.0 – 2.2	-5.0 – -3.0
Arc_3	34.7	26.5	29.9	8.2	2.3	-2.1	37.2	24.4	1.2 – 3.1	-2.9 – -1.5
Arc_4	33.0	28.1	30.3	4.9	3.9	-3.7	35.1	26.4	2.8 – 5.4	-4.5 – -2.8
Arc_5	33.1	28.5	30.5	4.5	3.9	-4.1	34.8	26.8	3.0 – 5.2	-5.0 – -3.1
Arc_6	35.2	28.9	31.6	6.2	1.8	-4.5	37.9	27.5	0.0 – 2.7	-5.8 – -2.8
Arc_7A	33.3	27.4	30.0	5.9	3.7	-3.0	35.6	25.8	2.8 – 4.8	-4.0 – -2.1
Arc_7B	34.1	27.5	30.3	6.6	2.9	-3.1	35.7	26.0	1.1 – 5.0	-4.4 – -1.6
Arc_8	35.2	27.0	30.6	8.2	1.8	-2.6	38.3	25.3	0.9 – 2.2	-3.3 – -1.8
Arc_9	35.6	27.7	31.2	7.9	1.4	-3.3	37.7	26.3	0.6 – 2.5	-3.8 – -2.7
Arc_10	33.5	28.6	30.8	4.9	3.5	-4.2	35.9	26.8	2.1 – 4.6	-4.8 – -3.3
Arc_11	35.9	28.9	32.1	7.0	1.0	-4.5	38.8	27.1	0.4 – 1.7	-6.1 – -3.0
Arc_12	35.2	28.6	31.5	6.7	1.8	-4.2	37.5	27.0	0.5 – 2.7	-4.7 – -3.3
Arc_13	34.8	27.4	30.7	7.5	2.1	-3.0	37.1	25.8	1.4 – 2.9	-3.5 – -2.0
Arc_14	35.5	27.0	30.8	8.5	1.5	-4.2	37.7	25.3	0.1 – 2.6	-3.5 – -1.9

worst thermal condition; best thermal condition; 1, outdoor climatic conditions; 2, indoor reference space

In contrast to maximum temperatures, all arcades are always found to be hotter than the outdoor environment during night-time hours, when minimum temperatures occur (Table 3). Differences in mean minimum air temperature between arcades and the outdoor environment are at a range of -4.5 to -2.1°C, while maximum increase of minimum temperature against minimum temperature of the external environment is equal to 6.1°C (Arc_11). The warming effect observed in arcades is attributed to the narrow sky view of the case studies, resulting from the enclosure of the roof and side walls, which inhibits nocturnal radiative cooling. These results are in line with the findings reported in other studies (Malaktou, et al., 2016; Tsiros & Hoffman, 2014). The regression model between daily minimum outdoor air temperature, i.e. T_{min_out} and the difference between minimum outdoor air temperature and minimum temperatures of arcades, i.e. T_{min_out}-T_{min_arc}, shows mainly a weak to moderate degree of relationship in the patterns of variation (R^2 = 0.00–0.78) (Table 4).

Table 4. Linear regression results for arcades' (a) cooling effect ($T_{max\_out} – T_{max\_arc}$) with respect to T_{max_out}, (b) warmin effect ($T_{min\_out} – T_{min\_arc}$) with respect to T_{min_out} and (c) T_{fluct_arc} and T_{fluct_out} during the whole monitoring period[1]

	T_{max_out} -T_{max_arc} with respect to T_{max_out}		T_{min_out} -T_{min_arc} with respect to T_{min_out}		T_{fluct_arc} with respect to T_{fluct_out}	
	Slope, *b*	Det. Coef., R^2	Slope, *b*	Det. Coef., R^2	Slope, *b*	Det. Coef., R^2
Indoor	**0.98**	**0.92**	**0.82**	**0.81**	**0.06**	**0.03**
Arc_1	0.28	0.75	0.23	0.52	0.55	0.83
Arc_2A	0.29	0.81	0.02	0.00	0.57	0.62
Arc_2B	0.28	0.71	0.07	0.02	0.55	0.53
Arc_3	0.21	0.61	0.16	0.30	0.76	0.81
Arc_4	0.33	0.67	0.27	0.51	0.43	0.69
Arc_5	0.33	0.69	0.40	0.72	0.43	0.70
Arc_6	0.26	0.73	0.59	0.78	0.65	0.60
Arc_7A	0.29	0.76	0.20	0.50	0.54	0.79
Arc_7B	0.49	0.61	0.40	0.41	0.31	0.33
Arc_8	0.18	0.62	0.15	0.28	0.72	0.84
Arc_9	0.20	0.52	0.15	0.25	0.64	0.73
Arc_10	0.35	0.71	0.25	0.49	0.42	0.79
Arc_11	0.16	0.46	0.31	0.51	0.62	0.82
Arc_12	0.28	0.76	0.25	0.51	0.64	0.83
Arc_13	0.19	0.65	0.23	0.51	0.70	0.88
Arc_14	0.28	0.58	0.22	0.43	0.63	0.68

[1] Regression is performed using daily data

Table 3 indicates that mean diurnal temperature fluctuation of arcades is significantly lower than the corresponding value of the external environment. It varies from 4.5 to 8.5°C, while in the case of the outdoor environment, it equals to 12.6°C. This dampening effect, which enables greater thermal stability, is attributed to the effective shading, the insulation of the arcade roofs, the high thermal mass materials and compact built forms of both the arcades and the surrounding urban environment. Table 4 shows the results of the linear regression between the daily air temperature fluctuation of the outdoor environment and the daily air temperature fluctuation of arcades. The model shows a good degree of relationship in the patterns of variation in most cases (R^2 = 0.33–0.88). Values of the slopes vary between 0.31 and 0.72, which means that every 5°C increase of daily outdoor fluctuation may correspond to a rise of daily fluctuation of arcades from 1.6 to 3.6°C.

Architectural form and thermal interrelations

This section investigates the relation between the architectural characteristics of arcades, i.e. the DoE, and their thermal behaviour (Figs 1A & B). The statistical analysis of the environmental data during the entire monitoring period, indicates a good degree of relationship in the patterns of variation between the DoE and mean maximum temperatures of arcades (R^2 = 0.76) (Fig. 1A). This implies that DoE affects the level of cooling inside the examined spaces; the higher the DoE, the stronger the cooling effect. The value of the slope equals to -0.12, which means that increasing the DoE by 10 units, mean maximum temperature drops by 1.2°C. At the same time, the regression analysis that was performed between the Degree of Enclosure (DoE) and the mean temperature fluctuations of arcades indicates a good degree of relationship in the patterns of variation between the Degree of Enclosure (DoE) and the mean temperature fluctuations of arcades (R^2 = 0.79) (Fig. 1B). The analysis demonstrates that semi-open spaces with higher DoE result in lower air temperature fluctuations and thus greater thermal stability. Interdependence of DoE and mean globe temperature fluctuation has been reported in the study of Sinou (2007) in two case study locations, i.e. Siphnos island in Greece and Cambridge in the U.K. These findings confirm that the architectural form is a significant aspect in governing and controlling the microclimate of semi-open environments as other studies have also demonstrated (Tsiros & Hoffman, 2014; Sinou, 2007; Chun, et al., 2004; Potvin, 1997). The analysis of the case studies shows that semi-open spaces with DoE lower than 5 will result high temperature fluctuation, the spaces in the group with DoE between 5 and 15 will present medium temperature fluctuation, while the spaces with DoE over 15 will demonstrate low temperature fluctuation.

It is interesting to note that although orientation is a determinant factor of thermal performance, its impact on temperature fluctuation and maximum temperatures of arcades is not clearly established (Figs 1A & B). Bearing in mind that arcades are located within a densely built environment, one could claim that the orientation effect is weak because arcades are protected from solar radiation by the surrounding urban fabric. Another explanation relates to the fact that increasing the DoE, the effect of orientation on thermal performance weakens.

A number of arcade spaces (Arc_1, Arc_5, Arc_10 and Arc_11) which have been excluded from the regression analysis, do not perform as expected. Arc_1, Arc_5 and Arc_10 lie below the line, representing the relationship between DoE and mean maximum temperature and below the curve, representing the relationship between DoE and mean temperature fluctuation. This means that at a given DoE, these spaces present lower temperature fluctuations and lower maximum temperatures compared to the rest of the sample. These discrepancies may be attributed to the surrounding urban morphology and thermal control systems. More specifically, Arc_5, which faces a compact, shaded enclosed backyard rather than a street, seems to benefit from its more favourable microclimatic conditions. Despite its low DoE, Arc_1 achieves considerable reduction of the undesirable solar heat due to the fact that is located on a narrow North-South, well-shaded street with limited openness to the sky. The thermal performance of Arc_10 may be explained by the operation of ceiling and standing fans that remove the stale, hot air from the arcade. Arc_11 showed the highest mean maximum temperature among the sample, despite the fact that it has a high DoE. This could be attributed to the significant heat absorbed by the roof, since Arc_11, does not have upper floors, as opposed to all other arcades, which would provide additional thermal insulation.

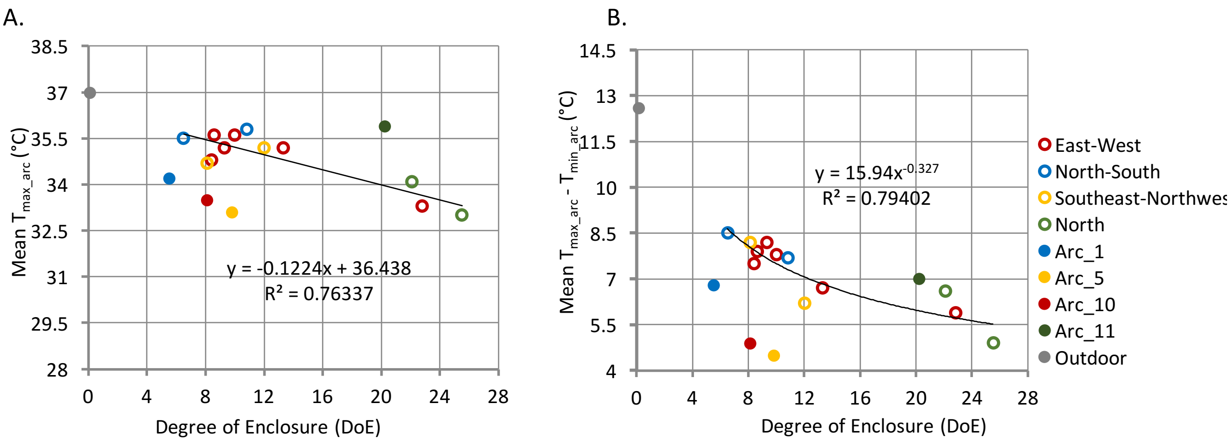


Figure 1. Linear regression results between DoE and A. mean maximum temperature (T_{max_arc}), B. mean air temperature fluctuation ($T_{max\_arc} - T_{min\_arc}$)

Conclusions

The present paper presents a quantitative examination of arcades' thermal behaviour in the summer and the links between architectural form and thermal behaviour. Arcades are found to be positive climatic elements in the summer Mediterranean climate. The low-tech, passive, climate-conscious design of such spaces may prove quite informative for contemporary architecture. Because of their environmental advantages, they can be exploited as models for the development of sustainable planning practices.

A strong cooling effect has been found to be associated with these spaces, indicating their importance in ameliorating summer climatic extremes. This cooling effect —estimated to have a maximum value of 5.4°C— was statistically evaluated and found to reach the maximum on extremely hot days. A strong cooling effect was also related to the Degree of Enclosure (DoE) and found to be greatest in spaces with high DoE; for every 10 units increase of the DoE, the mean maximum temperature dropped by 1.2°C. The assessment of the microclimate of semi-open spaces based on their architectural form, as presented in this study, could be used for the drafting of arcade design guidelines based on environmental criteria. For instance, a table providing a classification of semi-open spaces with regard to: orientation, materiality, degree of enclosure and obstructions, where information about the thermal impact of each parameter would be addressed, could provide a quick and simple tool for climate-conscious design proposals of urban areas. This would allow the creation of more thermally adaptive urban spaces which would encourage sociability and prolonged occupancy in the public domain.

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Design to Thrive

Performance evaluation of climate responsive buildings in India: two case studies from hot-dry and composite climate zones

Sanyogita Manu[1], Gail Brager[2], Ann Dennis[2]

[1] CEPT University, Gujarat, India, SanyogitaManu@cept.ac.in
[2] Center for the Built Environment, University of California, Berkeley, CA, USA

Abstract: India has a rich tradition of climate responsive architecture throughout its five distinct climate zones. Designing climate responsive buildings is challenging, requiring an understanding of building physics, as well as the manner in which buildings are designed, constructed and operated in a given cultural context. The process becomes more difficult with the ever-increasing comfort expectations. This paper is based on a study that was initiated in 2013 to evaluate the thermal performance of climate responsive buildings in a quantitative way. Several modern institutional and office buildings in warm-humid, hot-dry, moderate and composite climate zones, where a wide range of passive and hybrid design strategies was deployed. Two of these case studies are presented in this paper to evaluate the performance of solar chimney with evaporative cooling and cavity walls. In addition to the measured variables, performance was compared using a calculated 'comfort exceedance' metric derived from the neutral temperatures calculated from the India Model for Adaptive Comfort (IMAC).

Keywords: Passive/ climate responsive buildings, Solar chimney, Evaporative cooling, Cavity walls, India

Introduction

Natural ventilation is a technique of passively-designed architecture that provides fresh air for occupants and reduces internal cooling load, improving occupants' comfort without the energy burden of mechanical systems. Solar chimneys are one method for utilizing buoyancy-driven ventilation. There are many contemporary examples of solar chimneys in commercial buildings, and some of the most frequently cited examples include the Inland Revenue Centre in Nottingham, UK, the DPR Construction Office in Phoenix, Arizona, the Waseda University Honjo Campus in Honjo City, Japan, and the Ocean City Comfort Station and Performing Arts Stage in Ocean City, Maryland

There are two buildings with solar chimneys whose performance has been analyzed and widely disseminated: the Building Research Establishment (BRE) in Garston, UK and the Building and Construction Authority (BCA) Academy in Singapore. BRE was completed in 1996 and has three-stories of a narrow floor plan with operable windows and stacks on the south facade. Riain et al. (1999) analyzed the BRE building with measurements of ventilation rates and environmental conditions. They found satisfactory comfort and air quality conditions, fulfilled ventilation requirements across occupied space, and increased air intake from chimneys during warm, still days. The results of the temperature difference across the stack were less than expected, a top-to-bottom gradient of 2°C. They also found the thermal mass of the stack releases its storage of daytime energy during the night. BCA was retrofitted in 2009 and is one of six interconnected three-story buildings awarded for zero-net-energy achievements. It has four solar chimneys and vertical ducts on the west façade. Tan and Wong (2012) analyzed the BCA building with air speed and temperature measurements. They found acceptable thermal conditions according to calculated PMV and PPD. On hot days, the chimney had a 17°C top-to-bottom temperature difference and was found to increase classroom airspeed up to 0.49 m/s slowing the heating up of the space and increasing the cooling down by 1-2 hours compared to a reference region

In addition to these field studies, several experimental studies have been conducted on solar chimneys over the past 3 decades from theoretical, mathematical models and simulations (Bansal *et al.*, 1993; Ong and Chow, 2003) to small-scale, fine-bubble modelling techniques (Spencer 2001) and full-scale mock-ups (Afonso and Oliveira, 2000; Khedari *et al.*, 2000; Arce *et al.*, 2009) . The main objectives of these studies were to validate predicted calculations with empirical measurements, determine the most optimal parameters for the design of the solar chimney, and document its effectiveness at providing ventilation.

Cavity walls are another passive design strategy, referring to a building enclosure constructed as two layers with a gap. With increased focus on energy conservation in the 1970s, the filled cavity wall gained value in its insulating properties (Hens *et al.*, 2007). Hens et al. found that ventilation in the hollowed cavity had no effect in managing moisture, concluding a filled cavity wall is an effective choice for its other insulating benefits. Van Belleghem et al. (2013) present the alternative that ventilation can have a negative effect on the walls' moisture tolerance in high humidity. The research on the performance of cavity walls has been conducted in the UK and differs in its conclusions. There has been minimal research on the performance of cavity walls in warm climates.

Since the application of passive design strategies is dependent on climatic conditions, it is important to study the performance of these systems unique to the region. This paper examines two buildings in India: one located in a composite climate, fitted with solar chimneys and a low-energy evaporative cooling system; the other located in a hot and dry climate and using cavity walls as the primary passive design strategy.

Case Study Buildings and Methods

Building 1 is a public office building located in Panchkula in the northern state of Haryana, very close to Chandigarh, which is classified as having a composite climate (Bureau of Indian Standards, 2005). The building is designed around a large courtyard, which is open to sky. The total built up area is around 4000m^2 of which approximately 470m^2 is air conditioned. The main façade faces south and has five identical solar chimneys that start on Floor 1 and go up to the terrace, to provide ventilation in some of the non-air conditioned (AC) spaces. Two similarly designed solar chimneys are located on the south-facing side of the courtyard. The façade has high performance double pane, low-emissivity glazing, and is broken by several elements similar to overhangs, which seem to have been designed to protect the south façade from direct radiation in summer. The courtyard has fixed ferro-cement louvers on top, angled to cut-off the high summer sun, and misters located on top to provide evaporative cooling in the hot and dry months. They are designed to work in conjunction with the solar chimneys, by drawing the cooled air from the courtyard into the rooms served by the chimneys.

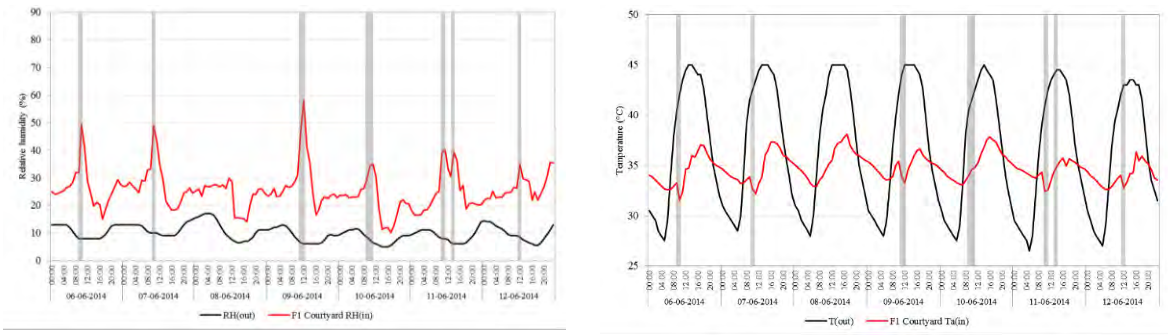
Building 2 is located on the outskirts of Ahmedabad in Gujarat, a hot and dry climate (Bureau of Indian Standards, 2005). The building has a total built up area of 2500m^2 with spaces such as classrooms, library and computer room, administration, multi-purpose halls and residential spaces for students and staff. The building is configured with more massing on the south-west, which provides shading to the open and semi-open activity areas located on the north-east. Parts of the building are subterranean and the ventilated cavity walls are constructed from load-bearing bricks, with the outer face left exposed (un-plastered). All spaces are naturally ventilated, with operable windows and ceiling fans.

Monitoring was done for a full year in each building. Air temperature and relative humidity were monitored using HOBO data loggers. Globe temperature was monitored in selected spaces. For Building 2, instantaneous measurements were taken using a Testo 410-2 anemometer (air velocity) and an Extech HT30 meter (air and globe temperature and relative humidity) measurements. Meteorological data for Chandigarh was requisitioned from an online weather source[1]. For Ahmedabad, data from a local weather station was used.

Results

Building 1: Solar chimneys & evaporative cooling

For brevity, only a sample of the full year of monitored data is presented here. Figure 1 shows temperature and humidity conditions for a week in June, representative of extreme summer conditions. The two most important passive strategies deployed in this building are the solar chimneys and the evaporative cooling from misters in the courtyard. In an ideal scenario, the misters would be turned ON during the hot and dry months. Figure 1(a) plots the relative humidity outdoors and in the courtyard, near the location of the misters. Except for Jun 8, which is a Sunday, one sees an increase in the relative humidity in the courtyard every day at around 9am, suggesting this is when the evaporative cooling starts. It then appears that the system is turned off 1-3 hours later, after the relative humidity reaches close to 50% or more. The periods when the misters are on are indicated using grey bands. Comparing these periods to the graph of air temperature outdoors and in the courtyard in Figure 1(b), an increase of 15% in relative humidity due to the misters leads to a reduction of 1.5°C in air temperature.



(a) (b)

Figure 1(a) plots the relative humidity outdoors and in the courtyard, (b) plots the air temperature outdoors and in the courtyard

Figure 2 plots the air and surface temperatures inside the solar chimney located in the courtyard. The black line is the outdoor temperature for those days, collected from an online weather source for that city (which admittedly could be somewhat different than the actual on-site outdoor climate). The red lines are from the solar chimney wall facing south – the wall that has the glazing intended to get heated up to enable stack ventilation. The blue lines are from the the solar chimney wall facing north. Solid lines are air temperature and dotted lines are surface temperature. Both air and surface temperature were higher on the south wall compared to the north, indicating the effect of at least some solar radiation. However,

[1] http://www.worldweatheronline.com/

on comparing the south-facing temperatures inside the chimney (red lines) with the outdoor air temperature, the former seems to be uncharacteristically low for an element that is supposed to work on the principle of catching radiation to move the warm air up the chimney. This may be attributed to the fact that all chimneys are covered with high performance glazing, perhaps limiting the degree of warming and hence the buoyancy-driven ventilation that might have otherwise occurred.

Figure 3 plots the air and surface temperatures inside one of the solar chimneys located on the south-facing façade of the building, with the red lines from data on the inside of the south-facing wall and the blue lines from data on the inside of the west-facing wall. In contrast to Figure 2, one does not see much difference between the red and blue lines here even though one might have expected that inside surface temperature of the south wall should have been higher. This might indicate that the solar chimney may not be very well designed. Solar chimneys on the façade have high performance glazing on the south, similar to the chimneys in the courtyard. However, the chimneys on the façade are also shaded by horizontal overhang type elements on the façade. The cumulative effect of the shading and high performance glazing decreases the efficiency of the solar chimneys.

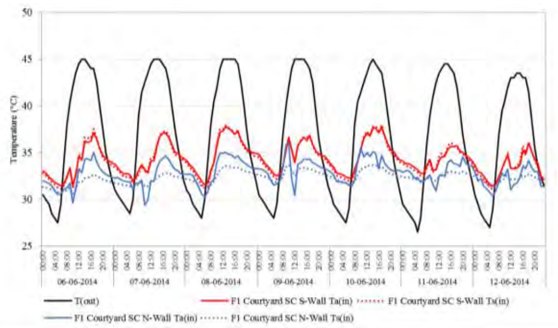


Figure 2: Air and surface temperatures inside the solar chimney located in the courtyard

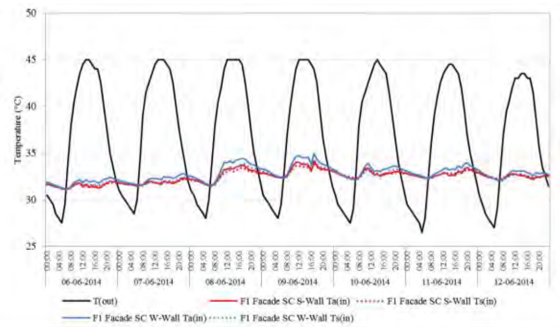


Figure 3: Air and surface temperatures inside the solar chimney located in the courtyard

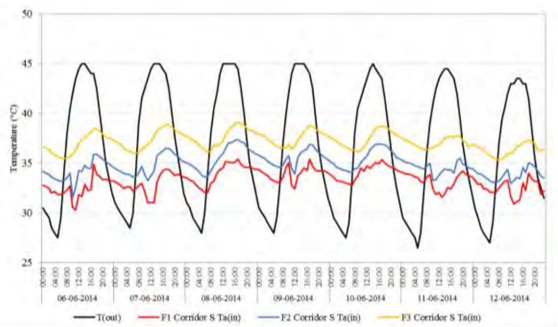


Figure 4: Air temperatures in the corridor on three floors

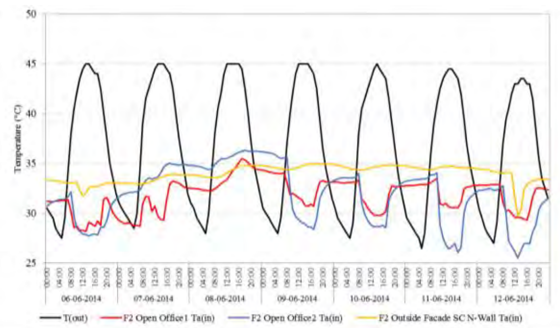


Figure 5: Comparison of air temperatures inside air conditioned and naturally ventilated rooms

Stack ventilation may be working in this building in two ways – (1) through the solar chimneys, and (2) through the courtyard. It is difficult to determine from the monitoring data alone what happens when both 'systems' interact. However, it is well known that for any kind of stack ventilation to work, there has to be stratification (or pressure differential). Figure 4 plots the air temperature in the corridor (open to the courtyard, as well as the rooms that have the solar chimney) at three heights (one on each floor of the building). As one might expect, corridor temperatures are higher as you move from Floor 1 to 3, indicating a considerable degree of stratification in extreme summer.

Figure 5 steps away from direct evaluation of the chimneys, and compares temperatures in rooms that have air-conditioning (AC) (red and blue lines) vs. one which is naturally ventilated and served only by the solar chimney (yellow line). The graphs suggest that AC in office 1 (red line) is on for all days except Sunday (June 8), while the AC in office 2 (blue line) is on for all days except Saturday and Sunday. While the outdoor air temperatures rise as high as 45°C, the temperatures in the naturally ventilated room served by the chimney (yellow line) remains below 35°C. The design problems with the façade solar chimneys were mentioned in the preceding paragraphs. It is possible, therefore, that the relatively low temperatures inside the space being served by the solar chimney are not a result of effective solar chimneys but the evaporative cooling system in the courtyard, as well as the thermal mass in the building.

Building 2: Cavity walls

Figure 6 shows the performance of the unshaded, exposed cavity wall in Building 2 (detailed section shown in Figure 8), for a week starting on May 16, 2015 (representative of extreme summer). Outdoor temperature is represented by both the black line (from a local weather station) and the solid red line (measured in the open courtyard). The dotted red line is the external surface temperature of the wall facing the courtyard, which receives direct solar radiation since it faces south. The blue dotted line shows the internal surface (adjacent to the classroom space) temperature of the same wall and the blue solid line shows the inside air temperature. The cavity wall is made of an interior layer of 230mm brick, a 115mm cavity and a 115mm external brick wall (Figure 8). The cavity space is naturally ventilated throughout the year but was not accessible for monitoring. The classroom is also naturally ventilated and has operable windows and ceiling fans. The external surface temperatures seem to be uncharacteristically high, even for a wall that receives direct solar radiation. What is noteworthy, however, is the dampening between exterior and interior air temperatures, ranging from 5.2-9.3°C. The thermal lag varies between 1-3 hours.

Figure 7 is a similar graph but for a shaded cavity wall. The red lines show the external surface temperature (dotted) of the wall and the air temperature (solid) near the wall. The blue lines show the internal surface (dotted) and air temperature (solid) inside the classroom. The wall construction is identical to that of the classroom shown in Figure 8; the space has operable windows and ceiling fans and is naturally ventilated throughout the year. The effect of shading is quite obvious when comparing Figures 6 and 7, in that the external surface temperatures for the shaded wall are lower than the outdoor air temperatures during the day. Interestingly, the interior classroom temperatures (blue lines) are very similar for both spaces, suggesting that the ventilated cavity is very effective at insulating against the effect of the solar radiation. The dampening for this room is comparable to what was found in Figure 6, and ranges from 5.4-9.9°C.

Figure 9 compares the indoor temperatures of spaces that have different orientations and exposures. All these spaces are naturally ventilated throughout the year, and have operable windows, ceiling fans and the same envelope (cavity walls). The dormitory and computer room are located on floor two (the top floor) and are therefore affected by the exposed roof. That may explain the higher air temperatures in these spaces. The admin building is exposed on the south, east and partially on the west. Direct solar radiation may lead to consistently high temperatures. The library has the same orientation as the admin building but is shaded on south and west, hence the lower temperatures.

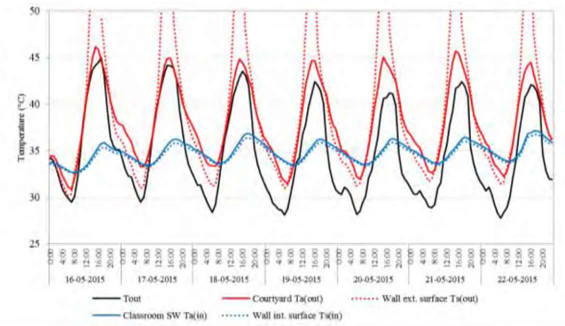


Figure 6: Air and surface temperatures of exposed cavity wall

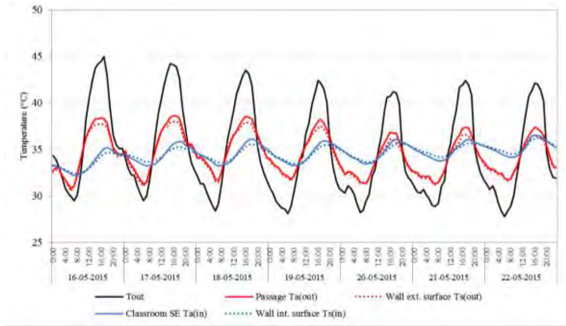


Figure 7: Air and surface temperatures of shaded cavity wall

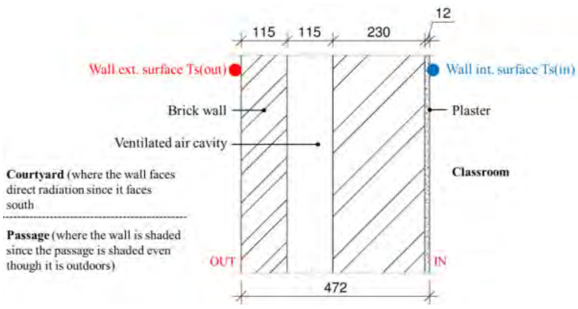


Figure 8: Cavity wall section

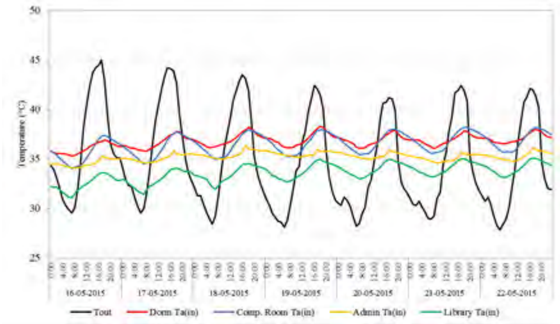


Figure 9: Comparison of air temperatures inside naturally ventilated rooms with different exposures

At 8 instances, we recorded instantaneous measurements for air and globe temperature, air velocity and relative humidity in three spaces – the classroom and library on the ground floor and the dormitory on the first floor. We then calculated operative temperatures (see Figure 10), which ranged from 22.7°C to 34.3°C. We compared these in Figure 10 to the acceptability limits (solid for 90%, dotted for 80%) from two different adaptive comfort models - black lines for IMAC (India Model for Adaptive Comfort) (Manu *et al.*, 2016) and red lines for ASHRAE Standard-55 (ASHRAE, 2013). For most instances, the operative temperatures were within the broader IMAC 80% acceptability limits. But they do not meet the narrower ASHRAE-55 adaptive model acceptability bands, except for a few data points from the classroom and library.

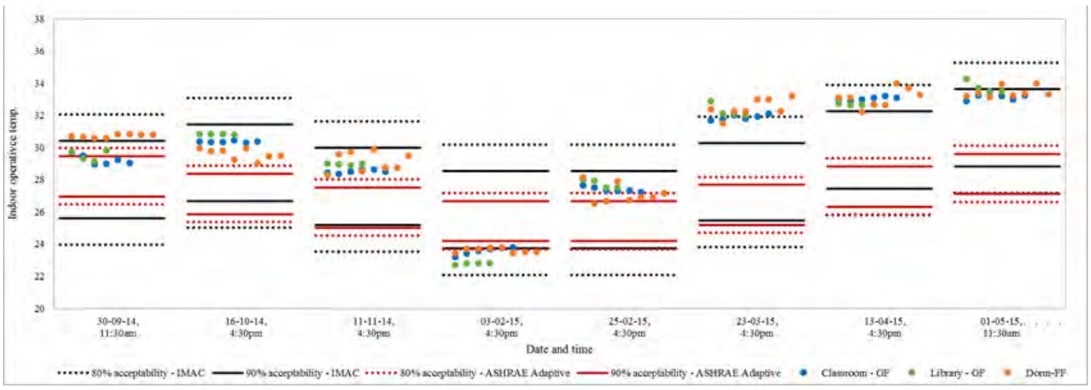


Figure 10: Evaluation of instantaneous indoor operative temperature based on the IMAC and ASHRAE-55 adaptive models

Comfort exceedance

The heats maps in Figures 12 and 13 were generated for the naturally ventilated spaces in buildings 1 and 2. The color coding indicates the "comfort" bin assigned to each hour based on the IMAC model for naturally ventilated buildings. The map for Building 1 was plotted from April 2014 to March 2015, and from August 2014 to August 2015 for Building 2. The wide "uncomfortably warm" bands in both figures are indicative of the days when the outdoor temperatures exceeded the applicability limits of the IMAC model for naturally ventilated buildings. That means the outdoor temperatures were too high for natural ventilation to mode to provide comfort conditions indoors. For that reason, the cells have been indicated as uncomfortable.

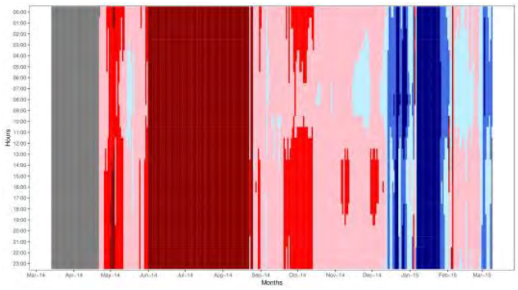


Figure 11: Heat map showing thermal comfort exceedance based on IMAC-NV model for Building 1

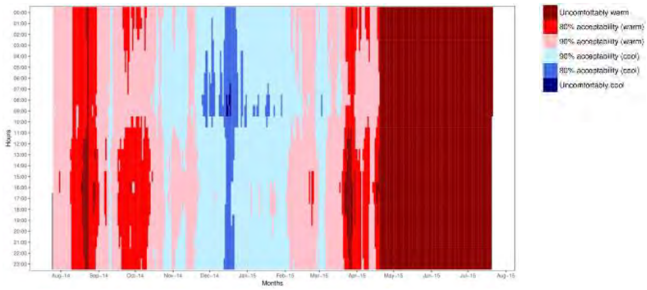


Figure 12: Heat map showing thermal comfort exceedance based on IMAC-M model for Building 2

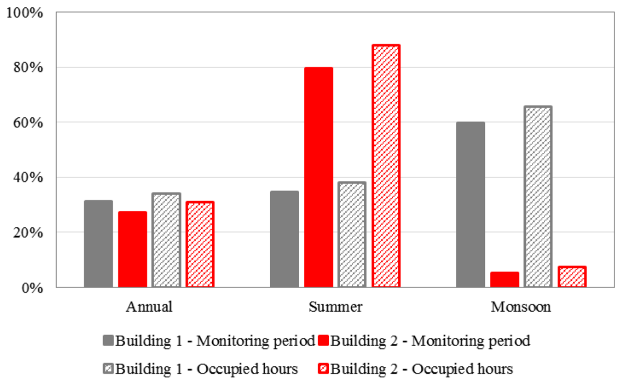


Figure 13: % Discomfort hours

The percentage of discomfort hours in each building were calculated for the duration of the monitoring period (Figure 13). Although the outdoor climate and building designs were quite different, the % discomfort was comparable in both buildings when looking across the whole year. There was slightly higher discomfort during occupied hours (31-34%), which is important since these are day-time use buildings. Binning the data into seasons revealed more interesting patterns. During the summer, Building 2 (cavity walls) exceeded the IMAC limits 88% of occupied hours compared to 40% discomfort hours in Building 1 (thermal chimneys). During the monsoon, the pattern was reversed and Building 1 had more than 65% of occupied hours being uncomfortable compared to only 8% in Building 2.

Conclusion

Two distinct buildings, located in different climate zones, were monitored for one year. In Building 1, the evaporative cooling system (misters in the courtyard) resulted in a reduction of 1.5°C in air temperature with a 15% increase in relative humidity during the extreme summer conditions. The stratification between floor 1 and 3 near the courtyard was around 3.5°C, a result of stack ventilation induced by the courtyard. The solar chimneys are covered with high performance glazing, with those on the façade having additional shading elements. It is suspected that these features keep the air inside the chimney from reaching the high temperatures needed to generate a powerful stack ventilation. This seems to be a lost opportunity due to poor design or execution. However, in spite of these flaws, the building is able to maintain a difference of 10°C between indoor (naturally ventilated spaces) and outdoor temperatures during extreme summer conditions. Comfort exceedance calculations for this hot and humid location showed that discomfort hours were less than 40% in summer, but exceeded 60% in monsoon. Results from Building 2 show that the cavity wall is an effective insulation against direct radiation. The building had very low discomfort during the monsoon, but that may also be explained by the predominantly dry weather of this location.

Acknowledgement

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Ideal windows sizes for different orientation in a wind driven ventilated buildings

Talita Andrioli Medinilha-Carvalho[1] and Lucila Chabel Labaki[1]

[1] Department of Architecture and Building, State University of Campinas, Campinas, Brazil, talita.medinilha@gmail.com

Abstract: Wind driven ventilation is a passive cooling strategy that can be a powerful ally to reduce energy consumption in buildings, but it requires specialized knowledge and time investment. In order to make it more available to designers reliable and simplified guidelines are necessary. However, current ventilation standards require further developments since they only regulate minimal air change rate or percentages of window area, without considering other important parameters. In this regard, we verified the influence of different configurations of window systems on the thermal performance of a wind driven ventilated building. The object of this study is a residential building configured as a "double H" located in Piracicaba, São Paulo State (Brazil). Several configurations were simulated with the software Energy Plus coupled with CFD (ANSYS CFX) and the index Adaptive Comfort Degree-Days was adopted as a thermal performance indicator. It was shown that proper window dimensions depend on the window location and building orientation. The work provides simplified guidance to the windows design, thus, it stimulates the quality of the built environment and contributes to decreasing energy expenses with artificial conditioning.

Keywords: fenestration sizing, natural ventilation, wind driven ventilation, CFD analysis, thermal comfort.

Introduction

Design taking advantage of the wind driven ventilation is a recommended strategy to reduce energy consumption in buildings (Givoni, 1992; Lamberts et al., 2008; Rivero, 1986) . Nevertheless, to make proper use of this resource it is required an advanced knowledge in the field and time-consuming simulations. Thus, to allow greater applicability of this resource guidelines that simplify the process of dimensioning wind driven ventilation systems, as well as to approach the most relevant factors for natural ventilation are necessary. Such factors are the topography, the wind direction and velocity, the heat load, the proportion and shape of the building and window, the orientation, position in floor plan, type and area of the windows (Cóstola and Alucci, 2007; Lamberts et al., 2014; Toledo, 2006).

The current standards adopt a simplified approach to the topic, imposing a minimum number of air exchanges per hour, minimum ventilation area, or maximum air speed (Aflaki et al., 2015; Candido et al., 2010). These standards does not cover all the important aspects mentioned before and requires further study.

In addition to the standards, some researchers also address this issue by proposing methods for ventilation systems dimensioning for one face of a room (Khemlani, 1995; Suga et al., 2010), or hybrid ventilation and lighting systems in office buildings (Rupp and Ghisi, 2012), and different buildings proportion (Inanici and Demirbilek, 2000).

Other authors focus on the investigation of important parameters that indirectly lead to windows systems dimensioning guidance. The most investigated parameter in this regard is the WWR (window to wall ratio), which is mostly appropriated to evaluate its impact on the overheating, so that just a few researches explore the relation between the WWR and wind driven ventilation.

Zmeureanu (1988) relates WWR to the cost benefit of various types of thermal insulation and considers natural ventilation in the Montreal climate. Another case study evaluated air quality, thermal, acoustic, and visual comfort, in Nigerian hospitals(Stephen Nimlyat et al., 2015). Also, in Turkey, the ideal WWR for atrium and courtyards was analyzed (Tabesh and Sertyesilisik, 2016).

Although there is a discussion about some aspects of the windows design, it is noted that there are still some important factors related to natural ventilation that are not addressed, indicating the need for researches especially in the residential field.

In this regard, we investigated the ideal windows sizes for a low-rise building with wind driven ventilation considering different buildings orientations. The evaluated parameters are based on the previous research (Medinilha and Labaki, 2016), and are consistent with the scale of the models. A list of all parameters evaluated is presented: window area, the position of the windows on the floor plan, distance from the ground, and building orientation. To evaluate the best windows systems the building thermal performance was adopted, as recommended on Brazilian standard NBR 15220 (ABNT, 2005), instead of the wind speed.

Therefore, this study aims to contribute to reducing the deficit of information about sizing windows for the residential environment.

Method

The reference for this study is a residential building located in Piracicaba, São Paulo State (Brazil). It was modified by varying the area of the windows, and orientation. The data for this research were obtained through simulations, which occurred in two steps: the first one in CFD to obtain the pressure coefficients of the windows and then this information was fed to Energy Plus to perform the thermal simulation. This method improves the results accuracy because it allows considering different wind directions and intensity and building's heat load.

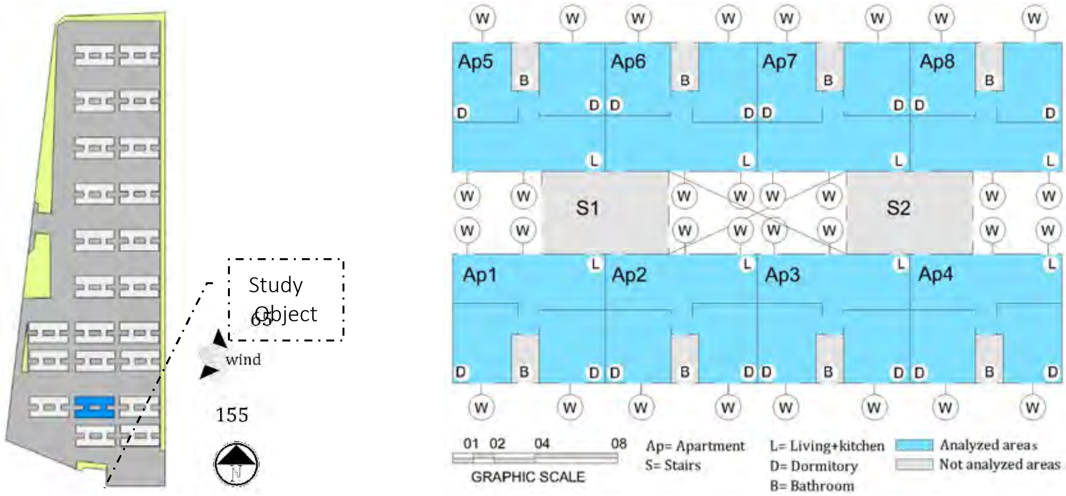
The city climate is described as humid subtropical - Köppen classification system (CEPAGRI, 2016). The average humidity is higher than 70% throughout the year; the maximum average temperature in the summer is 28,50°C and in the winter 26,19°C, the average minimum in the summer is 18,96°C and in the winter 12,48°C (Roriz, 2012a), which shows that even in the winter high temperatures are observed. Consequently, ventilation is needed throughout the year.

The wind speed varies from 4,80 to 0,44 m/s with an average of 2,46m/s (value used as the reference wind speed entry for the simulations). These data were extracted from Piracicaba climate archive (Roriz, 2012b) which were obtained at 10m above ground level. In order to consider the boundary layer effect a CCL (Common Command Language) expression (Cóstola and Alucci, 2007) was inserted on CFX, also the profile was considered neutral. After applying this correction, the resulted average inlet speed value were 1,06m/s and 2,27m/s, for the first and fourth-floor window level respectively. In addition, for Piracicaba, the wind prevailing direction is from 65° to 155°.

Model

For the selection of the reference building, the following conditions were considered: to have participated in a social housing program, to have an usual floor plan for the studied city, and to display uniform floor plan. Therefore Parque Piazza Navona residential complex was chosen not only because it meets those criteria but also it was the most populated. It is composed of 23 apartment blocks (as seen in figure 1-a). The location of the building at the residential complex (highlighted in figure 1-a) was selected for being the most obstructed one.

The reference case is a four-story building with typical materials and painted in light colors. As seen in the floor plan, shown in figure 1-b, the building is configured as a "double H" (two buildings shaped like an "H" positioned together) so that it forms a central courtyard and two side recesses. The apartments are composed of two bedrooms, a bathroom and a kitchen integrated to the living room. All rooms of the apartments were simulated except for the bathroom since it is of low relevance for thermal comfort.



(a) (b)

Figure 1. (a) - Location of the reference building at the residential complex; (b) - Floor plan of the Parque Piazza Navona residential complex.

Parametric variation

To determine the windows sizes to be tested, a calculation of window minimum (30% of the floor area) and maximum (60% of the floor area) area was performed by applying the currents Brazilian standards (ABNT, 2013, 2005) to the apartments. It was adopted the range from 0.6 to 4.0 m2 and the values were based on existing Commercial Brazilian windows and. The selected sizes are shown in table 1. Windows J60, J120 and J160 are the most common and inexpensive ones. In addition, the cases suffered variation on the parameters: orientation and window area, generating 24 case studies.

Table 1. Description of the simulated windows and ventilation areas.

NAME	N° OF SLIDING PANELS	ACTUAL HEIGHT [m]	ACTUAL WIDTH [m]	TOTAL AREA [m²]	VENTILATON HEIGHT [m]	VENTILATION WIDTH [m]	VENTILATION AREA [m²]
J60	2	1.00	1.20	1.20	1.00	0.60	0.60
J120	2	1.20	2.00	2.40	1.20	1.00	1.20
J160	3	1.20	2.00	2.40	1.20	1.33	1.60
J260	3	1.50	2.60	3.90	1.50	1.73	2.60
J330	3	1.65	3.00	4.95	1.65	2.00	3.30
J400	3	2.00	3.00	6.00	2.00	2.00	4.00

Computer simulation

For computer simulations, two software were used: CFX Ansys 16.2 (CFD simulation) and the Energy Plus 8.4 (energy simulation). The settings are described as follows:

CFX

In order to obtain the pressure coefficients 8 simulations were performed with the software CFX Ansys 16.2 for different wind incidences (further input to the software Energy Plus). The simulations were carried out by rotating the wind attack angle every 45°, starting from 0° up to 315°. To represent the obstructed surroundings all buildings of the residential complex were modeled. All internal partitions for the first and last floor (evaluated floors in the study) were modeled. Therefore, 64 pressure coefficients were extracted from each model, considering the central point of each window present in the studied rooms (identified with a “W” in figure 1-b).

To enable the simulation of various wind attack angles it was adopted an octagonal domain with a 674,43m diameter (50 times the object height) and 77,40m height (5 times the object height), according to the recommendations of (Cóstola and Alucci, 2007). This configuration resulted in a blockage of 0.009%.

Mesh independence tests were performed to ensure the accuracy of the model and to define the mesh. Several simulations were carried out by refining the mesh each time, This process continued until a finer mesh did not present significant changes in results, as proceeded in other rehearses in the field (Cóstola and Alucci, 2007; Lukiantchuki and Caram, 2012; Morais and Labaki, 2013). Thus, the mesh and the model’s domain were configured as shown in table 2.

Table 2. Adopted configuration for CFX ANSYS 16.2 simulation.

GLOBAL PARAMETERS		DOMAIN INPUT
SIZING		DOMAIN CONFIGURATION
numbers of cells across gap=	3	analysis type= stationary
face size=	2	heat transfer= isothermal at 20ºC
maximum size=	4	turbulence model= k epsilon
growth rate=	1,2	BOUNDARY CONDITIONS
		domain side walls= subsonic opening
		domain top= free slip wall
MESH CONTROL		domain ground and room walls= no slip wall
Face sizing		Roughness = smooth wall
Local =	building	CONVERGENCE CRITERIA
element size=	0.8m	maximum residual = 10-4
growth rate=	1,2	Iterations- min = 1; max = 600

Energy Plus

The models were constructed in SketchUp with the aid of OpenStudio plugin. The construction materials of the models were based on the reference building (listed in table 3), and the internal loads were established following recommendations (Pereira et al., 2013), see table 4.

Table 3. Materials used to compose the Energy Plus model.

	LAYER 1	THICKNESS [M]	LAYER 2	THICKNESS [M]	LAYER 3	THICKNESS [M]	TRANSMITTANCE [W/M2K]	ABSORPTANCE
Exterior Wall	Mortar	0,025	Concrete block	0,09x0,19x0,39			2,78	0,6
Interior Wall	Mortar	0,025	Ceramic block	0,09x0,14x0,24	Mortar	0,025	2,46	0,6
Slab	Concrete	0,14	x	x	x	x	2,7	0,3

Table 4. Internal loads used to configure the Energy Plus model.

TYPE OF LOAD	AMOUNT	UNIT

People	4	
Lighting	10.6	W/m²
Electric equipment	3.9	W/m²

Due to shape symmetry, it was possible to reduce the numbers of simulations by varying the orientation only at one-quarter of the circle (0°, 45°, 90°, and 135°). "Shading" objects were used to represent the surrounding's obstruction. The wind obstruction was already considered at CFD.

Natural ventilation was simulated in all studied apartments (see figure 1) using the object Airflow Network, with simulation control "Multizone Without Distribution", and pressure coefficients extracted from the CFD model. The maximum number of iterations was equal to 500 according to recommendations (Pereira et al., 2013). The windows were considered always open in order to understand the full potential to mitigate thermal discomfort through natural ventilation in different models.

Results and discussion

This study adopted as the performance indicator the Adaptive Comfort Degree-Days (for overheating) (McGilligan et al., 2011), which is calculated as the difference between the operative temperature and the adaptive comfort model of temperature for hot thermal sensation. This method allows to evaluate the intensity of discomfort throughout the day (Nico-Rodrigues et al., 2015); and is a well-known method for naturally ventilated environments.

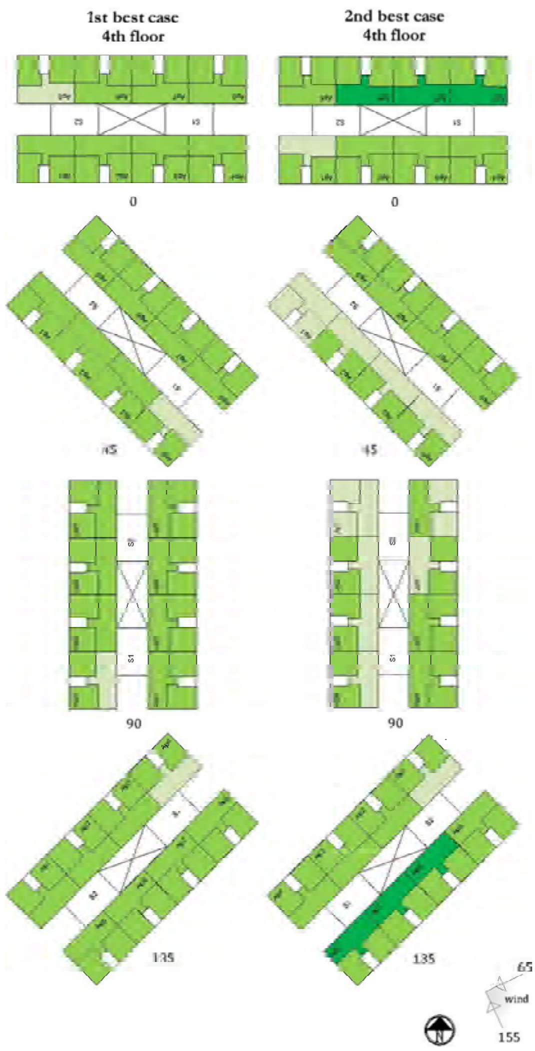
Table 5 presents the best and the second best window sizes, which means the models with the lowest values of Adaptive Comfort Degree-Days. The ideal window size was also identified in the floorplan, in this analysis only the fourth floor was considered as the first floor had uniform results (table 5). These results were classified by window size, as follows: 0,60 to 1,20m² - small; 2,60 to 1,60m² - medium; 3,30 to 4,00m² - big.

By analyzing table 5, we notice that for all orientations apartments on the first-floor require small windows (from 0,60 to 1,20 m²). It is also clear that for apartments on the fourth-floor the ideal windows for orientation 0° was similar to the recommendation for the 135°, and the orientation 45° should have windows similar to the 90°. The dormitory of the fourth-floor presented similar needs for every orientation, and the most frequent window size was medium. Only at the orientations 45° and 90°, the dormitory of apartment one required small windows as the second best (1,20m²). The best window sizes for the living room and kitchen are different for each model. At 0° and 135°, the ideal windows are from 0,60 to 3,30m². The wide range of sizes presented in these orientations can be explained by the winds predominance, as it becomes more clear in figure 2-c.

By observing the floor plan shown in table 5, it is clear that the courtyard does not influence the ideal window size, since all the windows with view to the interior (the ones on the recess and those on the courtyard) show similar behavior. Nevertheless, it is relevant to notice that this situation provides unreliable and poor quality ventilation because the airflow from cross the neighbour's apartments before arriving at the apartment located leeward on the courtyard.

Table 5. Best window sizes based on Adaptive Comfort Degree-Days for different orientations.

Orientation	0°		45°		90°		135°	
Best case	1st	2nd	1st	2nd	1st	2nd	1st	2nd
1st Floor_AP 01_dorm*	J60	J120	J60	J120	J60	J120	J60	J120
1st Floor _AP 02_dorm*	J60	J120	J60	J120	J60	J120	J60	J120
1st Floor _AP 03_dorm*	J60	J120	J60	J120	J60	J120	J60	J120
1st Floor _AP 04_dorm*	J60	J120	J60	J120	J60	J120	J60	J120
1st Floor _AP 05_dorm*	J60	J120	J60	J120	J60	J120	J60	J120
1st Floor _AP 06_dorm*	J60	J120	J60	J120	J60	J120	J60	J120
1st Floor _AP 07_dorm*	J60	J120	J60	J120	J60	J120	J60	J120
1st Floor _AP 08_dorm*	J60	J120	J60	J120	J60	J120	J60	J120
1st Floor _AP 01_sala	J60	J120	J60	J120	J60	J120	J60	J120
1st Floor _AP 02_sala	J60	J120	J60	J120	J60	J120	J60	J120
1st Floor _AP 03_sala	J60	J120	J60	J120	J60	J120	J60	J120
1st Floor _AP 04_sala	J60	J120	J60	J120	J60	J120	J60	J120
1st Floor _AP 05_sala	J60	J120	J60	J120	J60	J120	J60	J120
1st Floor _AP 06_sala	J60	J120	J60	J120	J60	J120	J60	J120
1st Floor _AP 07_sala	J60	J120	J60	J120	J60	J120	J60	J120
1st Floor _AP 08_sala	J60	J120	J60	J120	J60	J120	J60	J120
4th Floor_AP 01_dorm*	J160	J260	J160	J120	J160	J120	J160	J260
4th Floor_AP 02_dorm*	J260	J160	J160	J260	J160	J260	J260	J160
4th Floor _AP 03_dorm*	J260	J160	J160	J260	J160	J260	J260	J160
4th Floor _AP 04_dorm*	J260	J160	J260	J160	J160	J260	J260	J160
4th Floor _AP 05_dorm*	J160	J260	J160	J260	J160	J120	J160	J260
4th Floor _AP 06_dorm*	J160	J260	J160	J260	J160	J260	J160	J260
4th Floor _AP 07_dorm*	J260	J160	J260	J160	J160	J260	J260	J160
4th Floor_AP 08_dorm*	J260	J160	J160	J260	J260	J160	J260	J160
4th Floor_AP 01_sala	J160	J120	J160	J120	J160	J120	J160	J120
4th Floor_AP 02_sala	J160	J260	J160	J60	J160	J60	J160	J260
4th Floor _AP 03_sala	J160	J260	J160	J60	J160	J60	J160	J260
4th Floor _AP 04_sala	J160	J260	J160	J60	J160	J60	J160	J260
4th Floor _AP 05_sala	J60	J160	J60	J160	J60	J160	J60	J160
4th Floor _AP 06_sala	J260	J330	J260	J160	J160	J60	J260	J330
4th Floor _AP 07_sala	J260	J330	J260	J160	J160	J260	J260	J330
4th Floor _AP 08_sala	J260	J330	J260	J160	J160	J260	J260	J330



Subtitle: small 0,60-1,20m² medium 1,60-2,60m² large 3,30-4,00m²

*Average of the two bedrooms

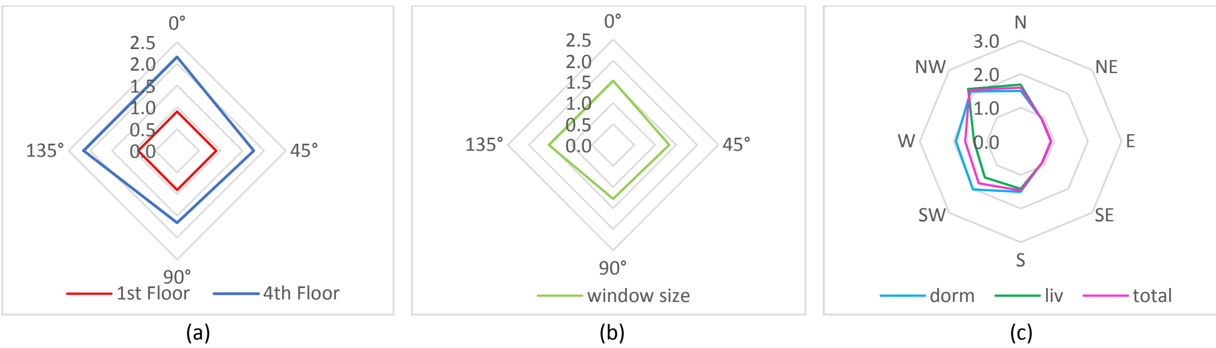


Figure 2. (a) – average ideal windows area of the rooms on the first and fourth-floor [m²]; (b) -average ideal windows area for different buildings orientations [m²]; (c) – average ideal windows area for different window orientations [m²].

Figure 2-a shows that window sizes for the first-floor are smaller than for the fourth-floor since apartments on the first-floor need less ventilation to reach the ideal temperature due to contact with the ground. In addition, windows on the first-floor do not show any influence of the building orientation, which was not the model for the fourth-floor. In the first-floor, the influence of the wind attack angle is reduced because at this height the wind speed is low for all directions.

In respect to the results concerning orientation, figure 2-b shows that for building orientations 0° and 135° the windows should be bigger. This phenomenon is better explained through figure 2-c, where it is clear that apartments oriented to northeast, east and southeast require smaller windows. These orientations coincide with the prevailing wind and also receive less solar radiation. It is worth of noting that the behavior of the living room and the bedroom are very similar.

Conclusion

Thus, it was possible to evaluate the sizing of openings from the viewpoint of thermal comfort in naturally ventilated buildings, indicating those models with the best thermal performance, therefore contributing to improve the knowledge of the openings design and consequently to reduce energy costs.

For the Piracicaba climate, the wind does not blow predominantly from a single direction but from a range of angles, thus we considered the range of wind predominance to evaluate its influence on different window dimensions. Therefore, at the process of designing windows in different climates, it is recommended to observe if this is a similar model or not. Even when the occurrence of prevailing winds is low, this direction influences the ideal window size, which means that windows oriented to the prevailing wind can be smaller than the leeward ones.

Analyzing the window size with respect to the floor height, it is noted that at the first-floor the optimal windows were smaller than for the fourth-floor and the ideal windows on this floor show little influence of their orientation. This happens because at the first-floor temperatures are milder due to contact to the ground and its lower exposure to the sun; on the other hand at the top floor the heat gain through the roof causes increased temperatures, thus requiring higher wind speed.

In addition, even if the courtyard has no influence on the size of the windows, it has not a reliable ventilation.

The sun exposition plays an important role on window dimensioning because window that receive direct sunlight tends to overheating, and consequently window size must be reduced, but with shading it is possible to have large windows improving the airflow. In some situations, when more ventilation is desirable but the large windows would cause overheating, shading devices should be considered. In this regard, future work could evaluate the influence of window shading devices on the ideal window sizes.

It is worth noting the strong influence of the climate on the results, so it is necessary to be very careful in applying these conclusions about the temperature ranges to other climates. Although this study only addresses one building geometry, the same methodology can be applied to other formats thus expanding the scope of the results.

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Analysis of sustainable collective housing in Jijel, Algeria: evaluation of resident satisfaction

Mia Mehibel[1] and Adrian Pitts[2]

[1] Researcher, School of Art, Design and Architecture, University of Huddersfield, UK, correspondence email Mia.Mehibel@hud.ac.uk;
[2] Professor, School of Art, Design and Architecture, University of Huddersfield, UK, email A.Pitts@hud.ac.uk;

Abstract: Worldwide, 40-percent of all energy used is consumed in the buildings sector. In this context, most developed countries have orientated their research and design to encourage energy efficient or green buildings; however comparable sustainable architecture is still in its early stages of exploitation in many developing countries. There are many pressures that can reduce emphasis on sustainable design in developing countries; for instance over one billion people worldwide still lack adequate shelter and suffer poverty, and Algeria is one example facing a pressing housing shortage. The socialist government that came to power after Algerian independence in 1962, considered this problem to be the major issue and this resulted in the initiation of major building programmes for social multi-storey housing estates. This research described in this paper reports on the quantitative and qualitative analysis of collective contemporary houses built in the city of Jijel. Detailed questionnaires were used with 30 residents in Jijel. The results showed that residents were more concerned with space issues while thermal comfort was neglected. Another interesting finding was that most of the interviewed residents would prefer to participate in the design of their houses; a process that would enable them to improve space and thermal comfort.

Keywords: Green buildings, sustainable dwellings, housing shortage, Algeria.

Introduction

In addition to enhancing human life and comfort, urbanisation and industrialisation have serious negative impacts on the environment. Global warming, industrial waste, and air pollution adversely affect the ecological balance (Memon, 2008). The most common definition of sustainability is 'meeting the needs of the present without compromising the ability of future generations to meet their own needs'. This definition was first used in 1987 in the Brundtland report entitled "Our Common Future" published by the United nation's World Commission on Environment and Development (WECD, 1987).

Worldwide, 40-percent of all energy used by humans is consumed in buildings sector. The increasing need to make buildings more energy-efficient can be explained by the limits of natural resources, national security, environmental concerns, climate change, social justice, and rising costs (Ramsdell et al.). In this context, most developed countries were oriented to research and design of 'energy efficient' or 'green' buildings since the energy crisis of 1970 (Zhu and Lin, 2004). However, there are many pressures that can reduce emphasis on sustainable design in developing countries; for instance over one billion people worldwide still lack adequate shelter and suffer from poverty (United Nation, 2012). Algeria is one example of a developing country facing a pressing housing shortage. The problem threatens cities with the spread of informal settlements and slums around all Algerian cities. The main causes of this dilemma were the acute rural exoduses to cities which took place in two different periods. The first was after independence in 1962 when people grouped in urban areas in order to ameliorate their living conditions(Benmatti, 1982). The second was during the Algerian civil war between 1990 and 2000 when people escaped from rural areas to live in more secure urban areas. However, not all new informal settlements are created by rural migrants as there has also been population growth. Consequently, Algeria witnessed a large spread of multi-storey housing after independence in 1962 (Daara, 2009).

Housing policy in Algeria

The new national housing policy adopted by the Algerian government since the five year plan of (2000-2004) aimed to improve living conditions for all social groups with special emphasis on low income groups in order to achieve better space occupancy and slow down rural exodus. This policy was based on diversifying housing types according to households' incomes(MHUV, 2012). Consequently, new housing types were established in order to meet the needs of intermediate income households who were not allowed to benefit from the social rental houses designated to low income families and could not afford to buy the expensive promotional (luxurious) houses. However, this policy failed to respond to the real demand of residents. Table 1 shows the ratio of demand and offer for different housing programmes in the province of Jijel. It indicates that there is a deficiency in housing offer in comparison with the number of demands, the number of demands is more or near double the cumulated programmes excluding Promotional public houses (LPP).

Table 1:*The demand and offer of collective housing programs in Jijel until 31/12/2016. (Source: Based on data from Housing department, Jijel)*.

Housing Programme	Cumulate (Offer)	Demand Number	Ratio Demand/Offer
Social Rented (LPL)	16981	40972	2.41
Promotional assisted (LPA)	6727	14700	2.18
Rent to sell (LV)	3600	7074	1.96
Public Promotional (LPP)	1000	426	0.42
Total	28308	63172	2.23

In fact, citizens are unable to benefit from government assisted houses due to households' low incomes and sometimes unemployment. Also, there is a big gap between salaries and housing prices. The ratio between the price of a house and the average annual income of a middle-income family is 9, which means that the family has to save her annual income for 9 years to be able to afford an LPA house (Bellal, 2009).

Survey for the evaluation of residents' satisfaction

Collective housing dominated the urban fabric of the city of Jijel without any consideration to the aspects of sustainability such as comfort, climate adaptation, the use of construction materials, and the respect of social and cultural values of the Algerian society. In fact, occupants' needs must be combined with modern technologies and sustainability potential in traditional architecture in order to create new sustainable cities that suit present and future expectations of the inhabitants (Mehibel et al., 2014). Consequently, the research project, of which this paper reports a part, is involved in assessing potential residents' satisfaction and integrating their views process. This research included quantitative and qualitative analysis for collective contemporary houses in Jijel using comparative analysis through descriptive, qualitative and spatial analysis for the case studies. Therefore, a number of detailed interviews have been carried out with thirty residents from three different collective housing estates in the city of Jijel, and the results are reported here.

The qualitative survey is divided into four different parts: Exterior environment, spatial comfort, thermal comfort and housing preferences. Each part contains a number of closed ended questions and open ended questions in order to evaluate the inhabitants' satisfaction of the design of their dwellings. The three case studies are governmental housing estates which are: Site 1 is the 400 social houses estate (400 LS) this kind of houses is entirely financed by the government; it is designated to low income households living in very bad conditions or those who don't own a suitable house. Site 2 is the 170 social participatory houses estate (170 LSP); this type of houses is designated to households with intermediate income who are eligible to a governmental non- refundable financial aid. Site 3 is the 375 promotional (Luxurious) houses estate (375 LP); this kind of houses is intended to comfortable households or individuals who are not eligible for any type of governmental financial aid.

Exterior environment

When the residents of the three estates were asked for the perception on the presence of green spaces, children playgrounds and squares for inhabitants where they can be gathered; most of the inhabitants considered that there is very little. Some inhabitants of the ground floors enclosed the surrounded areas adjacent to their blocks and plantedthem which created some sort of private external green spaces (Figure 1). In fact, this act is not permitted by the local municipality as such places should be public and shared between all residents. Also, the majority of respondents in the three estates claimed that there are no play areas and the children are playing in car parks and undesignated areas between blocks (Figure 2).

Figure 1: Public areas enclosed by residents of ground floor to make private green spaces in: a) 400 LS site and b) 375 LP site.

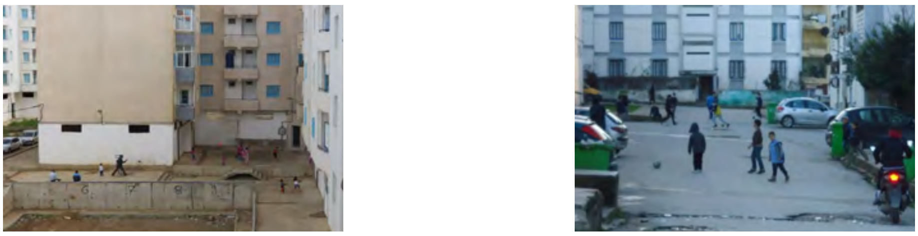

Figure 2: General and street views: a) 170 LSP and .b) 400 LS site.

Figure 3 shows children's playgrounds in the 375 LP estate which are in a poor state, this problem can be seen in many other collective housing estates in the city of Jijel. Residents can be blamed for such behaviour and the government should take action for the destruction of public places.


Figure 3: Destroyed children playgrounds in the375 LP estate.

The majority of respondents considered that there are no squares or areas where residents and neighbours can gather. When asked if they preferred having such areas, most residents agreed; only 20% in the 400 LS and the 375 LP estates disagreed; they were women who for cultural reasons prefered not to have such areas close to their houses in order to have more privacy in using the balconies.

Spatial comfort

Housing organisation preferences

All the apartments are organised around a corridor. However, The vast majority of respondents in the three estates (80% in 170 LSP and 70% in both 400 LS and 375 LP estates) preferred to have the dwelling organised around a central space rather than a corridor. They justified their answers that this organisation provided more space, better air circulation and more accessibility to the other parts of the house.

Size of the house

In the two social estates (170 LSP estate and 400 LS estate), the majority of respondents (70%) found the size of their apartments too small for their family needs, and all of them preferred to have one or two extra rooms to be used as a room for children and a dining room. Interestingly, 60% of respondents in the third estate (375 LSP) considered that the apartments are of the right size for their family needs 20% of them stated that the apartment is big and only 20% considered their apartment small. Just 20% of the respondents desire to have an extra room to receive guests. Table 2 represents the total living area of houses in the three estates. It is obvious that total living areas of the promotional flats is similar to social houses. However; residents in the promotional estate are more satisfied with the size of their houses.

Table 2: Area of the houses.

Estates	Living area (m²)				
	F3 (Living + 2 bedrooms)			F4 (Living + 3 bedrooms)	F5 (Living + 4 bedrooms)
170 LSP	70,39	68,45	69,99	-	-
400 LS	65,21			76,68	88.15
375 LP	68,66			80,95	93,40

Size of the different rooms

The majority of respondents from 170 LSP and 400 LS estates find the size of the living room and the other bedrooms small and all of them find the shape inconvenient to accommodating the furniture. In some cases they had to swap between the bedrooms and the living room in order to get more space area for children room or to get more space by rearranging the furniture in parents' room.

Conversely, in the 375 LP estates, the majority of respondents stated that the bedrooms have the right size and they can arrange the furniture the way they want. Also, just half of respondents find the size of the living room small and the other half find it about the right size. However, 70% of respondents find the shape inconvenient to arrange the furniture. Table 3 shows the area of the living room in the estate of 375 LP (16.99m^2) which is very small for a promotional house and even smaller than the area fixed by the Algerian regulations for social rented housing which is 18 m^2. That explains the fact that most residents close the loggias in order to gain more living area in the living room.

Table 3: Area of the living rooms.

Estates	Living area (m^2)		
	F3 (Living + 2 bedrooms)	F4 (Living + 3 bedrooms)	F5 (Living + 4 bedrooms)
170 LSP	19.66	-	-
400 LS	14.96	14.96	14.96
375 LP	16.99	16.99	16.99

Residents of the three estates where asked if there are any other activities they cannot do in their houses because there is not enough space. In 170 LSP estate, the number is more significant than the other estates (70 % in 170 LSP versus 40% in 400 LS and 375 LP estate) which mean that residents in 400 LS and 375 LP estates are more satisfied in terms of space and this can be related to the number of bedrooms. Some respondents answer that they cannot practice sport, or have family gatherings during social and religious occasions or receive guests. Table 4 shows that the areas of bedrooms in the three estates are very close even with the promotional apartments. However, people in this site are more satisfied in terms of spatial comfort as they have more number of bedrooms. So it can be concluded that residents do not need bigger areas of bedrooms but they want a larger number of bedrooms.

Table 4: Area of the bedrooms.

Estates	Living area (m^2)			
	Bedroom 1	Bedroom 2	Bedroom 3	Bedroom 4
170 LSP	12.31	12.74	-	-
400 LS	12.25	13.30	11.47	11.47
375 LP	11.02	13.34	13.80	12.45

Size of the kitchen

The vast majority of respondents in the three estates find the size of the kitchen small and they don't have enough space for work and to arrange different equipment. In some cases, residents in the three estates have to use bedrooms, corridor, bathroom and balconies in order to put the rest of their electrical equipment. Table 5 shows the area of the kitchen in the three case studies, it also shows that the kitchen in the 400 LS estate is smaller than the other sites.

Table 5: Area of the Kitchen.

Estates	Area of kitchen (sqm)		
	F3	F4	F5
170 LSP	10.41	-	-
400 LS	07.56	07.56	07.56
375 LP	08.29	08.29	08.29

Importance and use of the kitchen's loggia

The majority of apartments in the three estates have a loggia connected to kitchen. The loggias are used as an arrangement space, a place to dry clothes, put water tank, washing machine, the fridge and tabouna which is a cooker for traditional bread; some of them have been closed in order to gain more space to the kitchen (Figure 4), which shows one of the inconvenient consequences of closed loggia; the resident had to use the corridor to dry the clothes in rainy days (Figure 5).

Figure 5: Closed loggia in 400 LS estate.

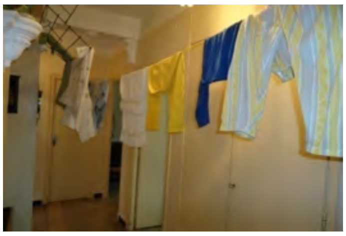

Figure 4: Drying the clothes in the corridor in a rainy day(closed loggia in the 400LS estate).

Thermal comfort

In this section residents were asked of their feeling of comfort in both summer and winter periods.

Summer comfort

More than half respondents in the three estates answer that they feel comfortable in their houses in summer. However, in 400 LS and 375 LP estates mainly all respondents are using air conditioners which opposite their feeling of comfort. On the other hand, just 10% of respondents in 170 LSP estate are using air conditioners which make their feeling of comfort more correct.

Winter comfort

In 170 LSP estate, all the interviewees don't feel comfortable in winter due to cold and the lack of natural gas to use heaters. Contrary to the other two sites where nearly all respondents stated that they feel comfortable in their houses during winter but all of them are using heaters.

Energy consumption

The results found in thermal comfort analysis help explain the energy consumption:

- The consumption of electricity in the 400 LS and 375 LPestates is approximately doubled in summer in comparison to winter as they all use air conditioners. However, the consumption of gas is much higher in winter than in summer as they all use heaters.
- In the 170 LSP estate, the price of electricity is similar between summer and winter as the majority of them don't have air conditioners.

Housing preferences

When residents were asked about their housing preferences:

- The majority of respondents wanted to change the house to an individual villa with a garden.
- More than half respondents wanted to participate in the design of their houses.
- In the three estates residents suggested to build cities with small number of houses, bigger apartments with green areas and children playgrounds.

Results

- The only different criteria between the studied social and promotional estates is spatial comfort; as people in the promotional estate are more satisfied in terms of space than the others; however, people want extra rooms to gain more comfort.
- Thermal comfort is not considered in the design of houses. However, residents were not concerned about it as they can afford their comfort with energy consuming appliances.
- Although, people are satisfied by their apartments in the example of the promotional estate, they prefer to have an individual villa with a court or a garden; and most of the interviewed residents prefer to participate in the design of their houses.

Conclusion

Housing policy in Algeria fails to respond to residents needs in both quantitative and qualitative levels. In fact, many problems are facing the housing sector and the most important issue is the serious imbalance between housing demand and the available supply. Unfortunately, a significant increase in the number of houses being produced is not possible, particularly after the economic crisis declared in the country in 2015 caused by the sharp decrease of oil prices. Also, the slowness of administrative procedures in most cases is one of the important causes that delay the completion and then the delivery of new projects.

In order to reduce the cost of projects the government can:

- Make better use of local workers, developers and professionals rather than importing them from overseas, an example of Rent to sell houses projects in Jijel; a total of 2000 houses are under construction by an international company using more than 200 foreign workers. The government could train local workers and professionals and this will reduce the rate of unemployment and also reduce the cost of houses.
- Integrate and encourage sustainable behaviours such as the use of recycled materials and renewable energies which can reduce energy consumption in different phases of housing projects.
- Integrate the new technologies and techniques in all fields of work in order to speed the administrative procedures in all stages of projects: Choice of land plot, design, and construction in order to deliver the houses in their deadlines.

In terms of qualitative issues; certainly it is not always possible to satisfy all people's needs but the government can find a method of work to integrate civic society in the process of design such as by surveys to assess the needs and preferences of future inhabitants.

- In terms of design; the exterior environment should be provided with green spaces, secure children playgrounds and squares for residents to be gathered, also, the state should penalise and strictly prohibit any behaviour that damages the exterior environment.
- The design of houses should consider bioclimatic parameters in order to build passive, low energy consuming buildings.
- The form of social LPL and LPA houses has been fixed by the government to a three-room apartment (living+ 2 bedrooms) with a little increase in the living area of the house from 68 m^2 to 70 m^2 ± 3%; this initiative aimed to avoid the increase in assisted

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Design to Thrive

Improving Building Fabric for Energy Efficiency in Hot Climates by Applying Passive Cooling Strategies: A Case Study for School Buildings - Towards environmental school buildings in hot, arid region

Sara Mohamed[1] and Siddig Omer[2]

[1] Faculty of Engineering, Architecture and Build environment, Nottingham University, Nottingham, UK, ezxsm@exmail.nottingham.ac.uk

[2] Faculty of Engineering, Architecture and Build environment, Nottingham University, Nottingham, UK, Lazsao@exmail.nottingham.ac.uk

Abstract: The demands for cooling in non-domestic buildings are rising throughout the world. This paper is concerned about the environmental performance of primary schools in hot climate, which affect the pupils' health, education and productivity. The study focuses on the thermal comfort within classrooms and the improvement of the building fabric by provision of a passive cooling system, as well as other passive ways that improve the classroom's thermal performance. It is common for school classrooms often to have poor thermal comfort and poor indoor air quality (IAQ).Computational fluid dynamics (CFD) simulations have been performed in order to examine the behaviour of the cooling wall system in reducing the effect of outside air temperature under different wind velocities in the summer period. Furthermore, different reductions in heat flux with air velocities have been examined by comparing the performance of the wall fabric system, both with and without passive cooling, and with the same geometry and the same physical characteristics and parameters. The results demonstrated that the proposed passive cooling, in conjunction with outdoor air, could significantly reduce the temperature and enhance the thermal comfort inside the classrooms. The performance of the natural wall ventilation with passive cooling system is an improvement in terms of cooling the classroom compared with the non-passive cooling wall system, since it allows the peak air temperature to decrease the temperature inside the classroom zone from 35-44C° range to just 26-22C° (5–18% to 50–61%) compared with peak temperature at 46-48C°

Keywords: Building Fabric, Passive and Low Energy Architecture, Ventilation, Thermal comfort.

Introduction

Constructions, buildings and, in particular, school buildings in developing countries such as Sudan are normally designed with little consideration to the effects of the climate. It has been established that the most significant purpose of a building is to deliver thermal comfort to its occupants. This becomes more important when it comes to the construction of school buildings, where the pupils need thermal comfort for their health, learning ability, and productivity. School buildings are among the most important buildings, and the majority are not given enough care and consideration. Children at primary level are very vulnerable to the indoor environment; this will affect their health and will not help them improve their skills. The climate is hot in summer and cold in winter. Classroom temperatures on a summer afternoon day can reach over 37C°-42°C. According to ASHRAE, the recommended thermal comfort for the dry "bulb" room temperature is around 22°–23°C with 50% relative humidity. The building envelope is the interface between the outdoor and indoor environment, and the amount of the energy required to maintain thermal comfort in buildings can be determined. One of the best options for saving energy in retrofitting the project and existing is through designing the building envelope in an energy conscious way. Educational buildings, i.e. school buildings, have particular concerns and the issues around energy require more attention because of their specific characteristics compared with other buildings. In fact, educational buildings represent a special case, mainly because of their specific occupants, activities and occupancy patterns, and knowing the students/children spend 25% of their time at school building Calautit and Hughes (2016) ,Barrett, Davies et al. (2015). Educational building is a good opportunity to promote building energy efficiency and environmental quality towards the pupils or occupants (P.O. Fanger 1970, Barrett, Davies et al. 2015). The most effective way to increase thermal comfort and energy efficiency in buildings is by means of acting on the element which constitutes the exterior–interior exchange system, controlling the heat transfer through the envelope (Dominguez et al. 2012.). The basic principle of the evaporative cooling wall system is achieved by the exploitation of the latent heat of evaporation of water to reduce the sensible heat of air and consequently its temperature. Based on this method, both direct and indirect evaporative cooling can be developed. When adapted, this principle dramatically decreases and sometimes even cancels out the cooling load in hot and warm climates (Carbonari et al. 2015). This paper addresses the potential of introducing passive technique to control the temperature and thermal comfort inside school buildings in hot dry climate. Moreover the develops and produces a base case design concept for passive cooling to reduce the temperature inside the classrooms, to identify and explore the possible effectiveness of adding passive cooling in the classroom fabric, in terms of reducing the temperature and enhancing.

Methodology

Description of the proposed concept

In the base cases design for the porous ceramic design, the ceramic itself is closed and the system is designed to have openings at the top and bottom of the wall. The schematic geometry of the system is shown in figures 1. The structure on the left is the wall with the inlet, the middle part is the porous ceramic and the part on the right is the indoor wall structure with the outlet in the bottom of the wall. The inlet should allow ambient air to enter, while the outlet should allow airflow directly into the classroom or the building. Air coming from the outdoors passes through the porous ceramic evaporator where it is cooled by evaporative cooling, and is drawn downwind by the bouncing effect and then enter into the indoor spaces where the cooling effect is required

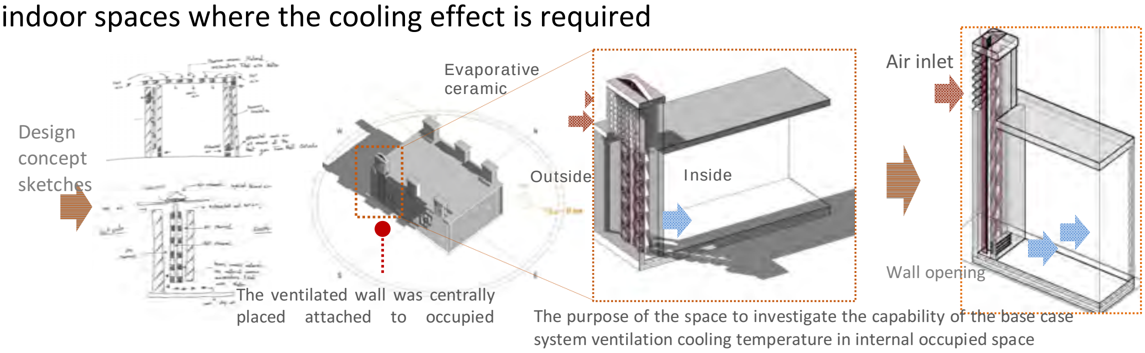


Figure 1-The base case primary design 3D perspective added to occupied space [classroom].

CFD Analysis -Design Detailed of the Geometry

The ventilated wall structure of (2.5 m) height with top and bottom opening with attached cooling wall is, centrally placed and attached a small occupied space with height, width and length of 1.5m, 2.5m and 1m. The purpose if this was to investigate the capability of the base case design in cooling and ventilation of the occupied space. The ventilated wall consists of environmental inlet on one side of the domain and opening at the top and bottom of the wall. The wall of occupied wall has an outlet opposing boundary passive cooling wall. The computational grid used for calculating the airflow and the heat flux within the ventilated cavity had a quadrilateral mesh with dimensions 0.5cm by 1.0cm within all the domains which contain air channels, the PCW [passive cooling wall], the outer layer of the subject facade, the inner wall space and the outer classrooms. A three-dimensional simulation model was developed to establish the natural ventilation flow path and the temperature distribution throughout the space of the classroom as demonstrated in figures 2. Passive cooling using a ceramic wall can be described as the heat flux in the fluent software. It is located between the external wall and the internal wall of the classroom

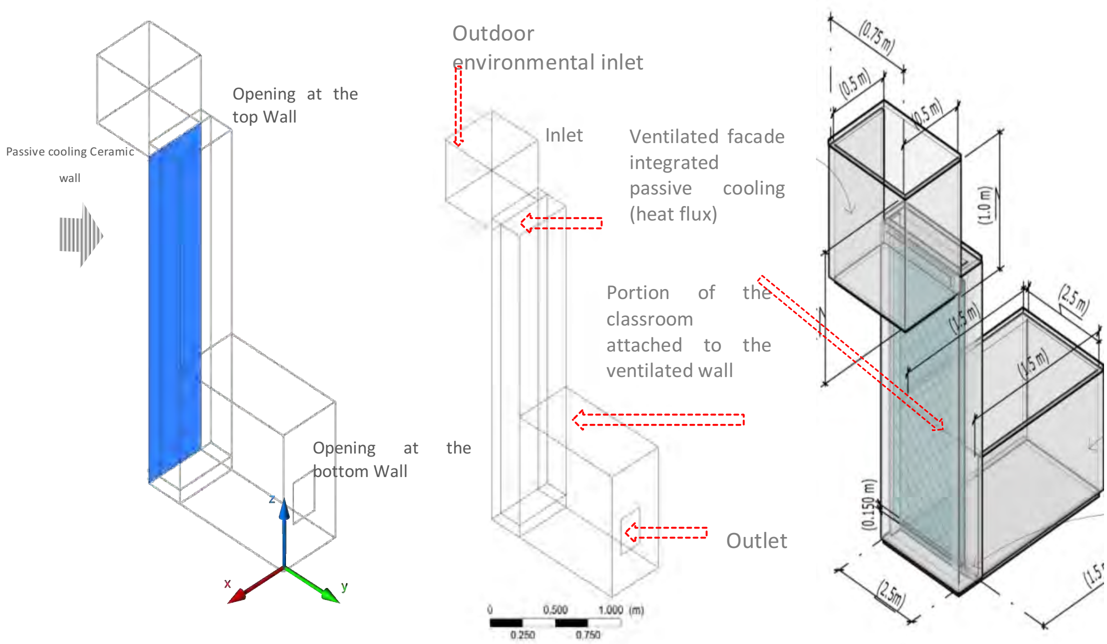


Figure 2-The 3D geometry of the ventilated facade integrated cooling wall used in the simulation.

Mesh description

The 3D CFD simulation model was built using meshing tools within ICEM. The meshing strategy was used to create conformal structure mesh that was considered as hexahedral cells. The benefit of using the hexahedral mesh was that the iteration run more smoothly and convergence could be reached more quickly, figure 3.

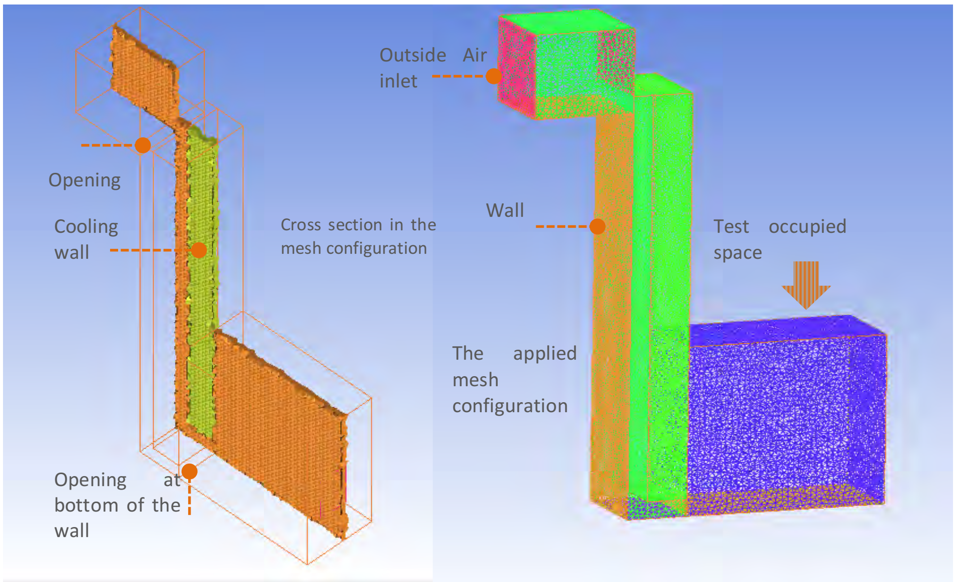


Figure 3: reduced scale perspective view of the base case geometry in its computational domain

Description of Boundary conditions

Cooling wall effect

The CFD is able to prescribe the surface heat flux inside the wall system of the classroom, as well as specifying the generated volumetric cooling rate of the cooling wall (Ibrahim Elfatih et al.2003). An equivalent heat flux of -5W/m2 was set to represent the 5, 10, W/m2 in their experiments.

Air temperature boundary condition

A velocity boundary condition of 0.2m/s, 04m/s, 0.6m/s and 0.8m/s were defined at the environment air inlet attached to the wall. The base case based on the air temperature of 36 C, determined by the local weather of Khartoum. The aim is to evaluate the local comfort environment of the corresponding occupied space of the class room with the reference to the local temperature and velocity distribution The table(1) below demonstrates air density, specific heat and thermal conductivity, for the temperatures values of 36° defined at fluent software

Table 1-The boundary conditions of the air properties at 36 Temperatures (Engineering Box 2016)

Temperature °C	Density	Specific Heat	Thermal Conductivity
	- ρ -	- c_p -	- k -
	kg/m^3	kJ/(kg K)	W/(m K)
36	1.127	1.005	0.0271

Simulation Results and discussion

Temperature variation

The effect of the incoming hot outside air on the cooling source resulting from PCW also had to be taken into account, and which was defined in the Fluent software as the heat flux. Figures 12 and 13 illustrate the behaviour of the temperature inside the wall at five different planes and locations parallel to the wall. The maximum temperature of 39.9°C was observed at the top of the wall. The surface temperature at the interior reference plane inside the classroom was set to a slightly lower value, while the lower temperature occurred at the bottom region of the plane, as seen in the figures. (Horizontal and vertical) .As can be seen in the results of the whole system, stratification of the temperature was identified, with higher temperatures externally at the top and lower temperatures at the bottom of the cavity in the wall. The results show the influence of the passive cooling air from the wall. The effect of the temperature horizontally and vertically in different positions are shown in Figures 4 and 5, and there is well-defined change from hot air to cold air indicated by the arrow in Figures below which demonstrated the occupied zone in the range in the comfort temperature

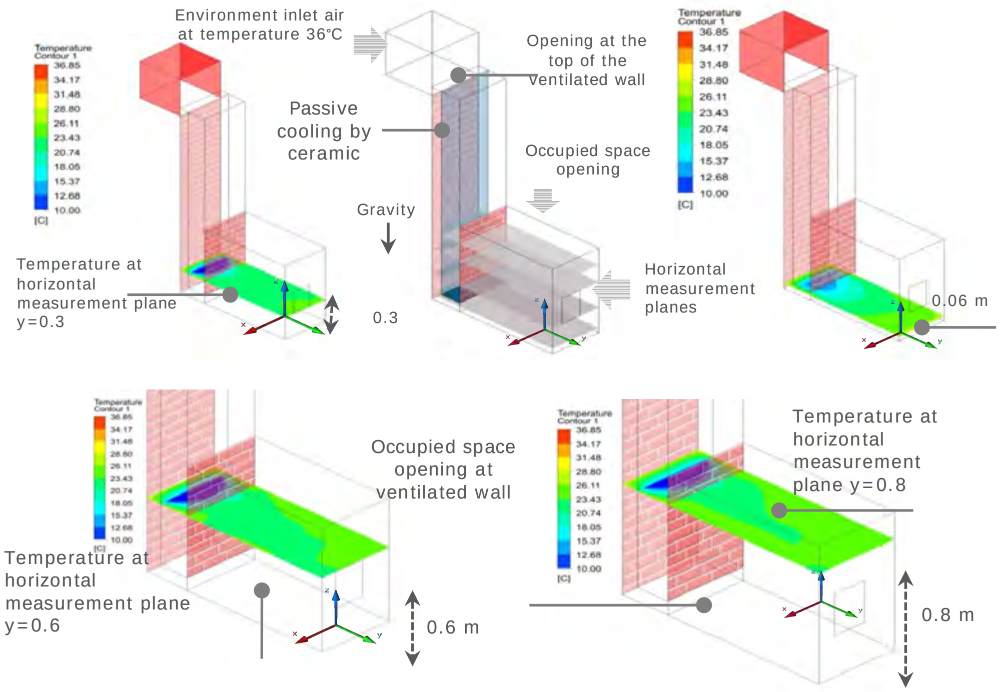


Figure 4-Temperature profile for ZX section through the classroom at different

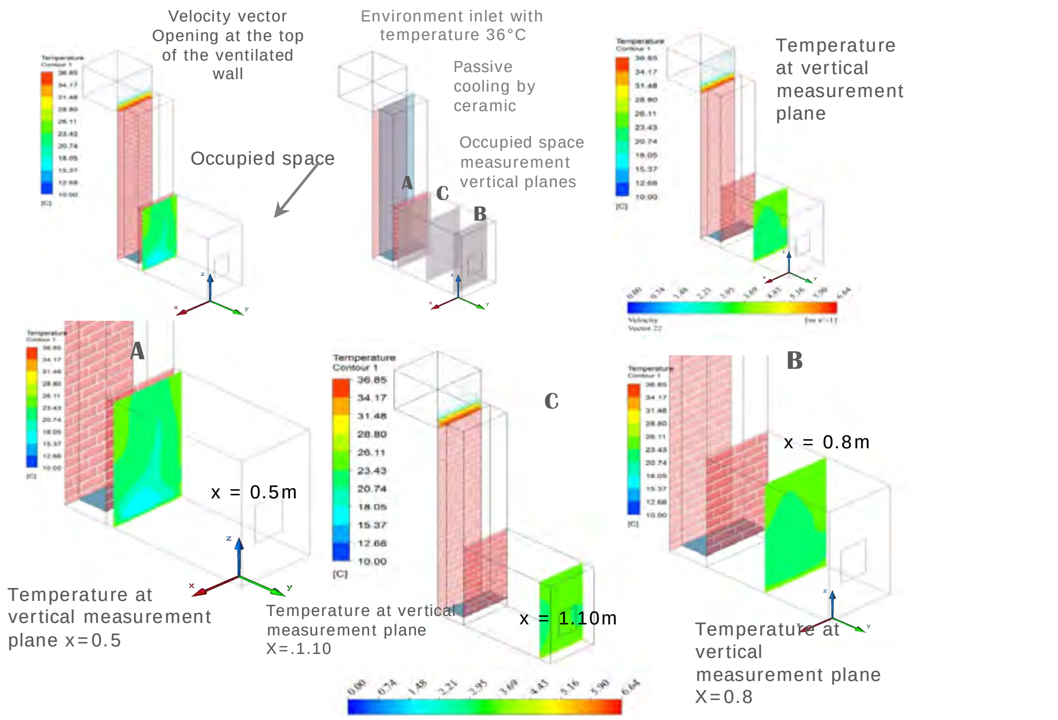


Figure 5-Temperature profile for YZ section plane through the classroom at different dimensions – demonstrates how the temperature decreases with passive cooling compared with the air entering the wall

The maximum temperatures are recorded with the ventilated wall without passive cooling reached values up to 40C° in the measurement plane, while the ventilated wall with passive cooling and have reached values close to the comfort temperature of 22C°-25C° as shown in the figure 6 and 7below with regards to the air movements within the system, the external wind flows normally, within the ventilated wall, with cool wall, from the top to downstream. It means that the air velocity within ventilated wall is mainly affected by the external wind. It is possible to highlight that when the wind velocity increases, the air velocities within the ventilated wall and in the space increased too.

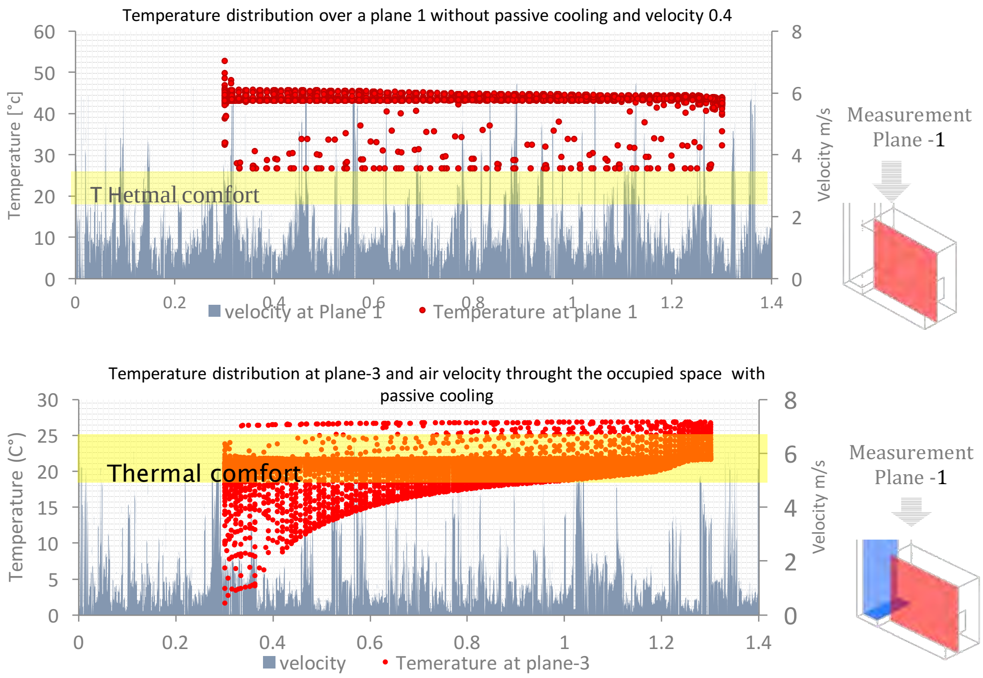


Figure 6: The temperature and velocity results in the measurement planes 1 at the occupied space with and without passive cooling at the ventilated wall

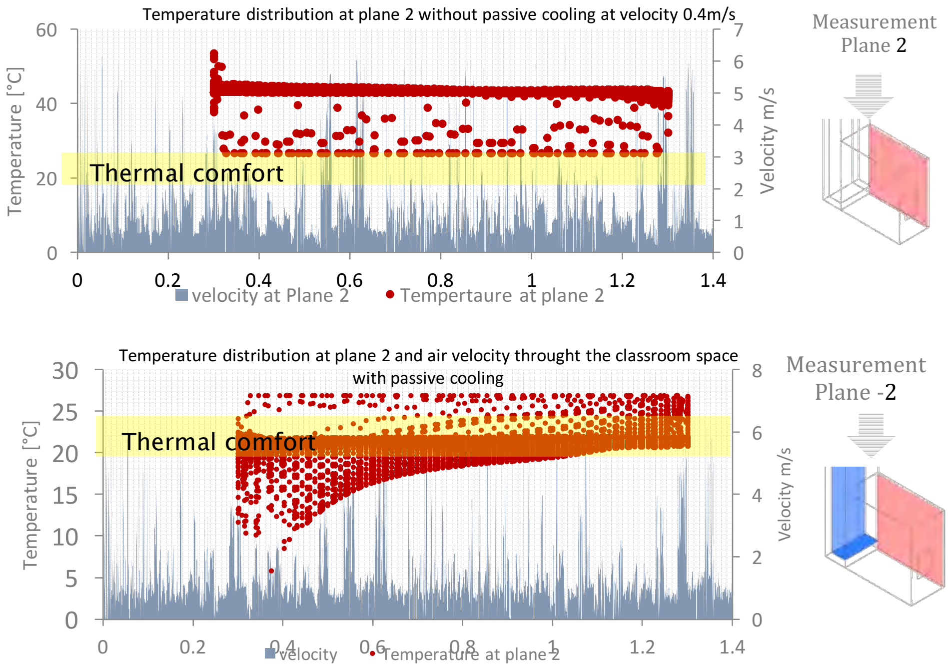
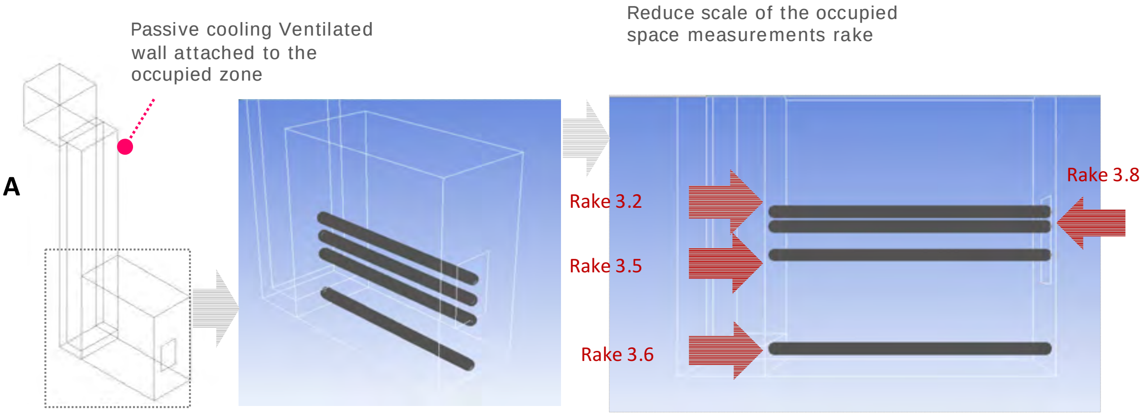


Figure 7: The temperature and velocity results in the measurement planes 2 at the occupied zone with and without passive cooling at the ventilated wall attached the base case design.

The analysis of the results indicated that cooling effectiveness improve with decreased when adding passive cooling to the wall fabric. It has also shown that ventilated cooling wall has higher performance by reducing the temperature by 61 % at 0.2m/s air velocity compared with other air velocity values. So a certain amount of air will pass by without contact the cool surface, figure 8. The results agree with (Jomehzadeh et al. 2016), stated that at low air velocity om 0.2 and 0.4 m/s the temperature gradient is high and decreases when air velocity increases.

A



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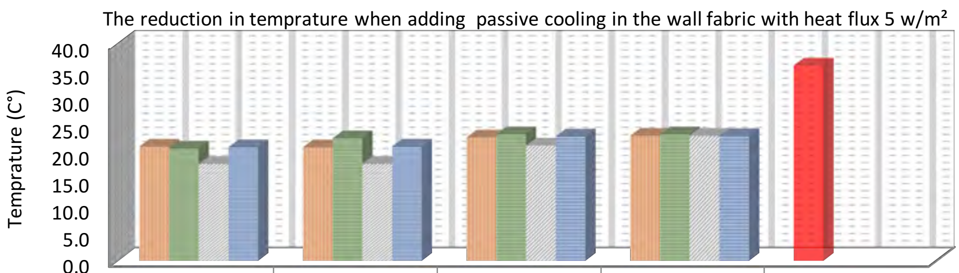

	velcoity = 0.2m/s	velcoity = 0.4 m/s	velcoity = 0.6 m/s	velcoity = 0.8 m/s	when Air temperature
Rake 3.2	21.0	20.9	22.7	23.0	36
Rake 3.5	20.6	22.6	23.3	23.3	
Rake 3.6	17.8	17.8	21.2	23.0	
Rake 3.8	20.9	21.0	22.9	23.0	

C

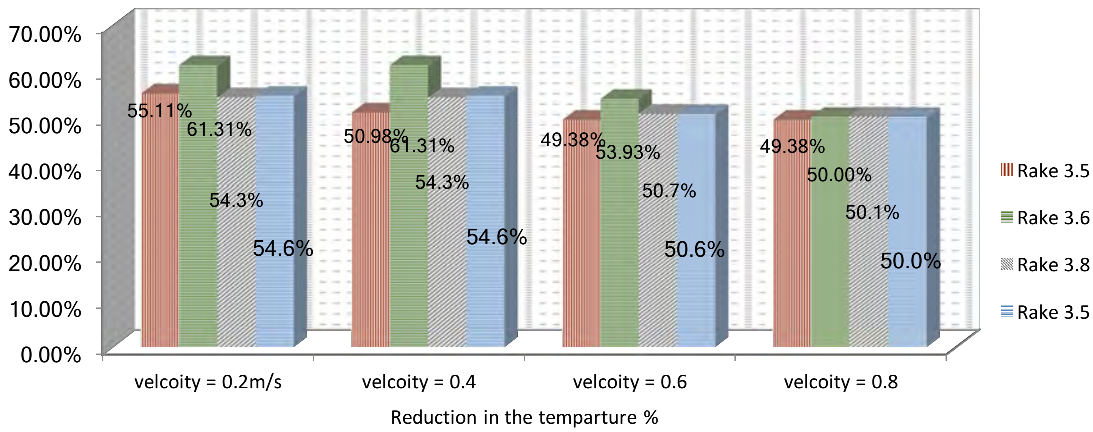

Figure 8: measurement rakes at the occupied space. (b) Temperature distribution at the measurement rakes along with air velocities (c) Reduction in the temperature at measurement rakes

Conclusion

The base case of the PCW was examined to assess the influence of cooling wall when added to the building fabric. The system has been assessed under varying inlet air speed. It was found that the PCW (passive cooling wall) was able to reduce the occupied room temperature compered to ventilated wall without passive cooling. For the base case with ventilated wall without adding passive cooling, the maximum temperatures are recorded in the measurement planes along with the width of the classroom space, are 39C°-41C°, compared with ventilated wall with passive cooling reach values at comfort temperature vary between 22C°-25C°.Overall, when comparing the effect of passive cooling wall PCW at envelope, we can observe a reduction in the temperature and consequence reduction in the classroom zone, which achieved thermal comfort level. The maximum total reduction in the temperature inside the occupied zone decreases between 49%-to 61 % at measurement rakes and plane, compared with only between 8%-18% reduction has been recorded in the temperature distribution at the measurement planes and rakes at the classroom space. Moreover such a comparison allows pointing out that, the PCW not only reduce the outside air temperature, but also shift the thermal wave that occurs in the envelope. The results showed the capability of the system in reducing air temperatures and deliver cooling following the addition of supplying recommended fresh air rates at the occupied space. As a final point, ventilated wall with Passive cooling process remain one of the least expensive technique, environmentally clean, fresh supply air and natural fragrance of air to bring dry bulb temperature to a move comfortable range particular in hot and dry climate.

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Design to Thrive

Principles and Tools for Bioclimatic Building Design - an applied review and analysis in cold climates –

Maria Coral Ness[1]

[1] Energy and Environment Group, Department of Architecture and Technology, Faculty of Architecture and Design, NTNU, Trondheim, maria.coral.ness@ntnu.no

Abstract: The comparison between climate and comfort represents a fundamental step for the implementation of energy efficiency in buildings. It determines the design strategies that are best suited for a specific climatic context, as well as the level of architectural complexity. In cold climatic contexts, this would suggest the use of compact shapes and extremely airtight and well-insulated envelopes, in order to minimize heat losses. However, when combined with high internal gains, these measures might cause overheating problems in the warm and transitional seasons. That is especially the case of office buildings, where mechanical cooling is included as default even in cold climates (Norway), drastically increasing their energy use. It is therefore becoming a necessity to consider there the adoption of passive strategies for cooling, traditionally identified with warmer climates. The aim of this paper is first to revise the existing methods and tools for bioclimatic building design, and then reflect on how these could be applied to assess the suitability of different passive strategies in relevant building cases. The first part of this research will be conducted through literature review. The second part will analyse relevant buildings in cold climates with especial focus on passive design, to reflect on how they could have been affected by the use of these bioclimatic building design tools.

Keywords: bioclimatic building design, passive strategies, thermal comfort, psychrometric chart, pre-early design stage

Introduction

As Reyner Banham postulated in his *Architecture of the well-tempered environment* (Banham, 1984), indoor comfort can be provided passively by the building, or actively by the use of energy. However, in order to design energy efficient buildings, passive strategies must be considered during the early design phase (Lechner, 2009). It is important as well to have a close collaboration between architects and engineers throughout the building design process in what is called "Integrated Energy Design" (Heiselberg, 2007). This is fundamental to ensure their mutual understanding of the project and the means to reach their common goals, making use of their different competencies and ways of thinking and working.

Problem statement

Traditionally, the choice of passive design strategies for climatic control in buildings was based on experience (vernacular architecture). Even today, the most common methods in use in many countries are experience-based (rules of thumb, building standards and norms, etc.). However, new building morphology, typologies (e.g. office buildings), elements and materials are challenging these pre-design methods to move towards research-based approaches.

This is the case of the Building Bioclimatic Charts that were developed in the second half of the 20th century. The most extended one is the Givoni-Milne bioclimatic chart (Milne and Givoni, 1979), that studies how to reach thermal comfort within the psychrometric chart. It considers as well the potential for extending the comfort zone by means of different passive design strategies for climate regulation. However, being developed primarily for warm climates, this method seems to be insufficient for identifying the correct measures for climate adaptation in energy efficient buildings in cold climates, under specific conditions (Finocchiaro et al., 2010). The use of extremely stringent envelopes, in combination with the high internal gains characterizing office buildings, is implying here the use of strategies for passive cooling, natural ventilation and solar control, once identified with warmer climates.

Purpose and methodology

In the first part of this paper, it will be offered a short review of the principles and tools for bioclimatic building design, reflecting on their suitability for cold climates. This section relies primarily on literature review.

The second part studies how these methods and tools could be adapted and applied to assess the suitability of different strategies for climate control in office buildings in cold climates, with especial focus on passive design. This is explored in two different case analysis.

Principles and tools for bioclimatic building design

The term *bioclimatic building design*, combining *biology* and *climate*, refers to the design of buildings in accordance to the local climate (Olgyay, 1963). Thus, the architectural design is linked to the physiological and psychological need for health and comfort. It also implies maximizing the utilisation of the available natural resources, prior to any energy supplement by active means.

Climate classification

The most widely used system is the Köppen-Geiger climate classification (Köppen and Geiger, 1930), based on temperature and precipitation. Following this scheme, a *cold climate* (represented by the letter D, also called *snow*) would be represented by an average temperature of ≥ 10°C for the warmest month and ≤ 0°C for the coldest month (-3°C according to some authors). The discrepancy in the temperature range for this type of climate is due to the fact that this classification is done according to the natural vegetation systems that are associated to each climatic zone (to represent long term mean climate conditions). The correspondence between these and the monthly mean temperature of the coldest month differs in some cases, e.g. for North America and Europe (Wilcock, 1968).

In the last years, a more specific climate classification for analysing the performance of energy efficiency measures in buildings was developed for the ASHRAE (Briggs et al., 2003b). Primarily designed in the United States for the implementation of energy codes and standards in buildings, it may also be applied in design guidelines and energy analysis in buildings. It uses SI units and climate indices based on the Köppen-Geiger system (Strahler, 1969), so that it can be adopted anywhere in the world. According to this system, a *cold climate* would include those regions with heating degree days (HDD) 18°C > 3000 (Briggs et al., 2003a).

The ASHRAE climate classification seems more adequate for energy analysis in buildings in general, which makes it more suitable for the present study.

Thermal comfort

An internationally-accepted definition of thermal comfort is ”that condition of mind which expresses satisfaction with the thermal environment” (ISO, 2006)

The evolution of indoor thermal comfort theories follow a continuous line from the first studies on thermal neutrality (static approach) conducted by Fanger (Fanger, 1970), to the ones on adaptive thermal comfort (de Dear and Brager, 1998, Humphreys and Nicol, 1998), to the newest developments towards transient thermal environments with the theory of thermal alliesthesia (De Dear, 2011).

The *static approach* is an analytical method derived from the assumption that the combination of skin temperature and core temperature of the body provide a sensation of thermal neutrality. The heat produced by the metabolism should be equal to the heat loss from the body. This approach to thermal comfort is based on the Predicted Mean Vote (PMV) and the Predicted Percentage of Dissatisfied People (PPD). It is used mainly for mechanically ventilated buildings, where thermal neutrality is an achievable demand.

The *adaptive approach* considers that contextual factors and past thermal history modify thermal expectations and preferences of the occupants in the building, through behavioural adjustment and psychological adaptation. It is a numerical method, used for natural or hybrid ventilation in buildings, where the occupants are tolerant of a significantly wider range of temperatures, according to seasonality.

The *transient approach* investigates thermal pleasure derived from environmental or metabolic transients. The thermal alliesthesia studies how thermal comfort in buildings can improve by allowing a broader variety of thermal solutions in different spaces, or in the same space in different moments in the year (seasonality) or the day, to mimic natural environments. This theory is still in an early stage of development.

Being this research focused mainly on the implementation of passive strategies for climate control, the adaptive approach seems to be the most relevant one here. Nevertheless, since its range of application is for mean monthly outdoor temperatures between 10°C and 34°C, which are not that common in cold climates, the static approach to thermal comfort will be considered in this study.

Building bioclimatic chart

The concept of constructing buildings in accordance to the climate is as old as humanity, but bioclimatic architecture was not recognised as a science until the Olgyay brothers started publishing their studies on climate-conscious design. They created the first Bioclimatic Chart in the early 50s and developed it in their book *Design with climate* (Olgyay, 1963). It was based on a Cartesian system with dry bulb temperature and relative humidity as coordinates, and shows the potential of wind and solar radiation on human thermal comfort. This method is suitable for application outdoors or for lightweight buildings in warm and humid regions, where there is little difference between indoor and outdoor conditions (Givoni, 1969), since it uses outdoor temperatures directly in the chart.

Soon after, Baruch Givoni adapted those concepts in his book *Man, climate and architecture* (Givoni, 1969), to create the first Building Bioclimatic Chart (BBCC). He used an Index of Thermal Stress (ITS) to evaluate the human requirements for the indoor environment to which the building design should respond. He also changed the graphical representation by using the psychrometric chart, to better show the hygrometric relations between the different parameters, and in a way that was already accepted and widely used by engineers since 1904, when it was first published by Willis Carrier (Gatley, 2004). In addition, he plotted into the chart the comfort zone and the areas of influence of different passive strategies (Milne and Givoni, 1979). This BBCC is still today the most widely used around the world, and it has been constantly updated according to new studies on the field. However, being developed for residential buildings with relatively light construction in warm climates, it does not take into consideration the effect of highly insulated and airtight envelopes in cold climates, especially when combined with high internal gains (office buildings).

There have been developed several computer programs to help analysing the building bioclimatic chart for its application onto energy efficient design. Amongst them, Climate Consultant© seems to be the most complete, up-to-date and user friendly. Developed by the UCLA Energy Design Tools Group, it is based on the theoretical work by Givoni and Milne (Givoni, 1969, Givoni, 1994, Milne and Givoni, 1979) and intended to support the book Climatic Building Design by Watson and Labs (Watson and Labs, 1992). It uses weather data in EPW format (Energy Plus Weather, exhaustive selection of weather stations around the globe, freely available) and can analyse it according to four different comfort models in the Psychrometric Chart. Yet it was designed to be applied on residential or small non-residential buildings in mild climates (Milne, 2015).

Case analysis

With the increased consciousness of living on a finite planet, there has been a proliferation of low-energy buildings, passive house, net zero emission buildings, zero emission buildings or even plus energy buildings. However, this number becomes drastically reduced when limiting the sample to office buildings in cold climates, with a special emphasis on energy efficiency through passive design strategies.

The cases chosen here for their level of innovation and integration, while offering a very different approach to energy efficient design in cold climates are: Manitoba Hydro Place (new built, Winnipeg, 2008) and Powerhouse Kjørbo (refurbishment, Bærum, 1979-2014).

This analysis will focus first on the local climate, to then study the spontaneously created microclimate (because of the stringent envelope and high internal gains) and the selection of passive strategies for climate control. The results will be then compared to similar conventional solutions, to understand the effect of the choices made under the design process.

Manitoba Hydro Place

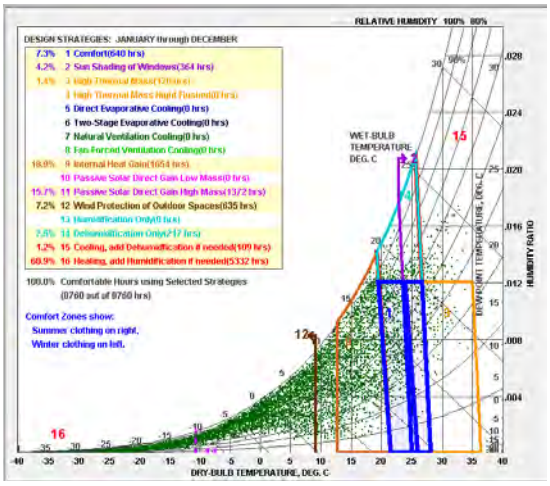

Figure 1. Left: bioclimatic chart for Winnipeg, from Climate Consultant© (Milne, 2015). Right: Manitoba Hydro Place, Winnipeg (Canada). Image: AIA top ten.

This office building is located in Winnipeg, Canada. It was designed by KPMB Architects in cooperation with Transsolar KlimaEngineering. The Köppen-Geiger climate classification for Winnipeg is Dfa: cold (T_{hot}>10, T_{cold}≤0), without a dry season and with hot summers (T_{hot}≥22). In the ASHRAE climate classification, it corresponds to zone 7: *very cold,* with an average of 5703 HDD (5000 < HDD 18°C < 7000). According to the BBCC and the 2030 Palette (Milne, 2015), the most relevant passive design strategies for this location are aimed at maximizing solar gains in combination with interior thermal mass, and minimising heat losses (low mass envelope, compact, airtight, super insulated and protected from the wind). See Figure 1.

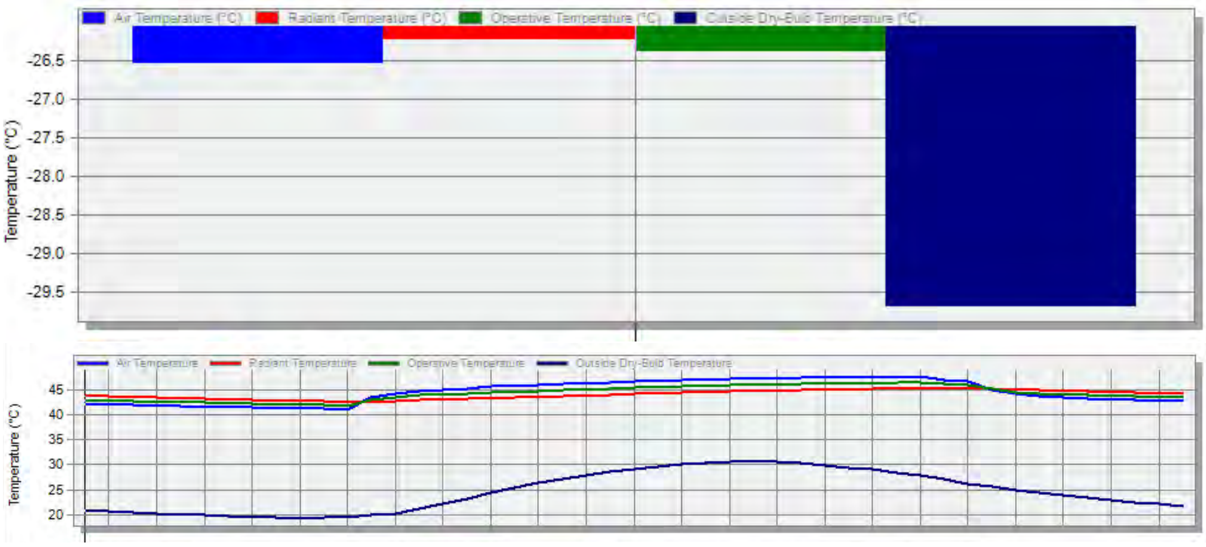

Figure 2. Winter and summer design temperature for the office block to the west, without environmental control systems (Energy Plus). We can appreciate that the indoor air temperature is respectively 3°C and 17°C higher than the outdoor air temperature. This is due to the effect of the solar gains and envelope alone in the first case, and in combination with the internal gains in the second case.

If we consider though the temperature increase indoors due to the effect of the solar gains plus envelope and internal gains, prior to the implementation of environmental control systems, it becomes quite relevant the incorporation of those two factors (envelope and internal gains) into the BBCC. For the west office block, the solar gains and envelope alone help increasing the temperature in just 3°C compared to the outdoor values in winter, while together with the internal gains produce a difference of +17°C in the summer. The indoor temperature becomes -26.5°C in winter and 47°C in summer, far away from comfort. See Figure 2.

The design of this building includes in fact several passive cooling strategies. It relies on a tempered buffer respiratory system with double-glass curtain walls to the east and west, and a series of three-floor-high atria to the north and six-floor-high atria to the south, to preheat the incoming air, minimising also the need for insulation materials. This system provides for fresh air all year round, in combination with a solar chimney for air extraction by stack effect, and elevated floors for air intake by displacement ventilation. In addition, each south atrium includes a water feature to humidify/dehumidify incoming air depending on the seasonal needs. It also utilizes a geothermal heat pump system for radiant heating and cooling via the exposed overhead concrete slab. Besides, it allows for operable windows and includes automated solar shading to prevent overheating. The U-values for the envelope are very low, ranging between 0.02 and 0.23 W/m^{2}K, and it is very airtight and relatively compact ($C=4.836*V_t^{2/3}S_G=0,63$ (Florensa and Roura, 2001)).

Due to its climate responsive design, its total energy consumption was of 138 kWh/m2 in 2011 , which implies a 66% of energy savings, compared to the Canadian Model National Energy Code for Buildings (Kuwabara et al., 2013).

Powerhouse Kjørbo

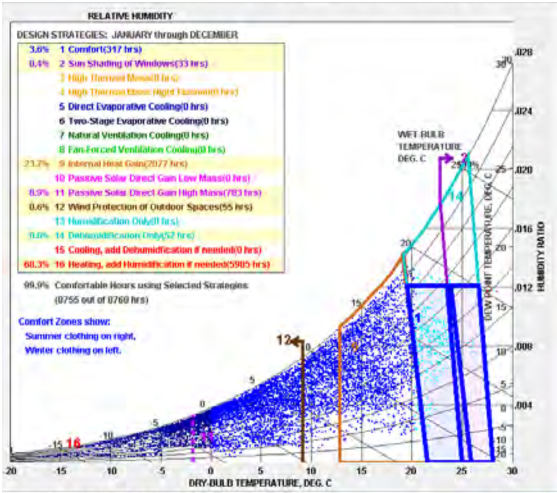

Figure 3. Left: bioclimatic chart for Oslo, from Climate Consultant© (Milne, 2015). Right: Powerhouse Kjørbo, Oslo (Norway). Image: Norwegian Green Building Centre.

This case is a refurbishment of two office blocks linked by the elevators and stairs. It is a pilot project for the Zero Emission Building Centre and was developed by the Powerhouse consortium as a ZEB. It is located in Bærum, near Oslo (Dfb), with a cold climate, without dry season and with warm summers ($T_{mon10} \geq 4$). Classified in ASHRAE as zone 5: *cool*, with 3700 HDD (3000 < HDD 18°D < 4000). The recommendations from the BBCC and the 2030 Palette are very similar to the previous case, though with a lower efficiency for thermal mass because of the higher cloud coverage throughout the year. See Figure 3.

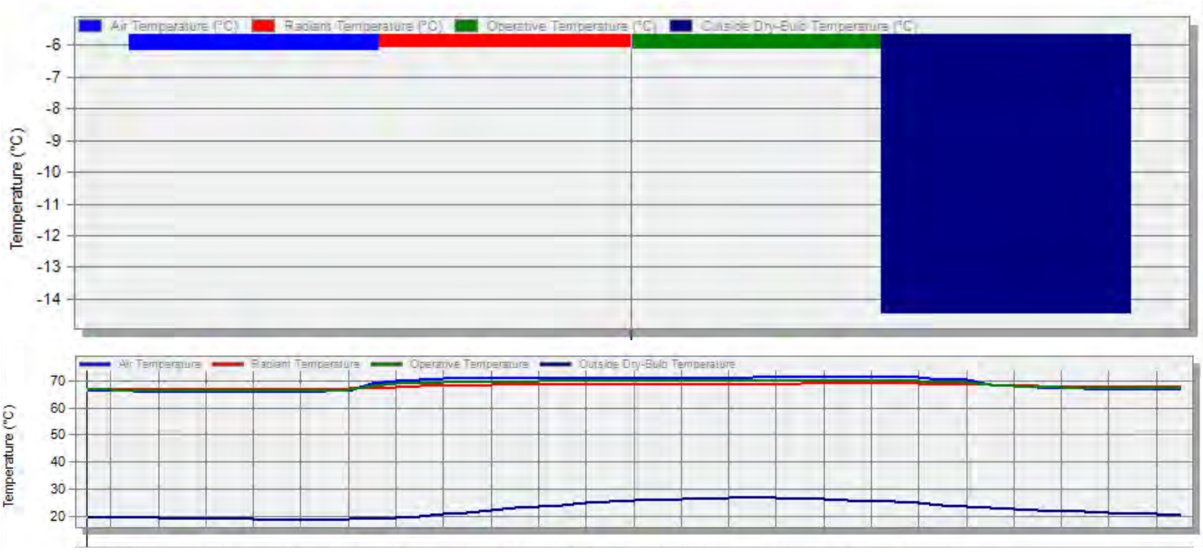

Figure 4. Heating and cooling design temperatures for the open landscape office without environmental control systems (Energy Plus). In this case, the difference between the indoor and outdoor air temperature is of around 9°C in the first case (envelope) and 40°C in the second (envelope and internal gains).

This office building is the case with highest compactness (0.76) and most stringent envelope, with an infiltration rate of just 0.23 ach and U-values between 0.08 and 0.8 W/m^{2}K (corresponding to the Norwegian Passivhaus Standard). This makes it possible to have a temperature increase in the winter of around 10°C indoors, compared to the outdoor conditions. See Figure 4. On the other hand, it also explains the extremely high air temperatures that could be reached indoors in the summer without environmental control systems. Then the highly insulated and airtight envelope does not allow the solar and internal gains to escape the building, creating a cumulative effect and reaching a temperature increase of around 40°C. This is due to the long summer days and the low angle of the sun that helps its penetration through the windows.

On the contrary, this building makes extensive use of thermal mass, leaving the concrete slabs exposed for thermal regulation in combination with the ventilation system (air intake from the façade on the top, distributing it in the central core, next to the concrete slabs for cooling of the structure). It maximizes daylighting as well, in conjunction with effective exterior solar screening to prevent overheating. Its building integrated ventilation solution makes use of the stairs and corridors for air distribution, allowing as well for opening the windows for natural ventilation in the warmer periods. Natural and hygroscopic materials with low emissivity help also in lowering the ventilation needs.

Together with the installation of sensors and a control system for lighting, equipment and installations, the total delivered energy was lowered to 45 kWh/m^{2}a including the operational energy for office equipment and server. As a reference, the Norwegian Building Code TEK-10 sets the total energy consumption for office buildings to 150 kWh/m^{2}a, so it achieved a reduction of 30% (Throndsen et al., 2015). If we exclude the consumption for the server and equipment to appreciate better the effect of the building envelope, it becomes around 20 kWh/m^{2}a, 80% lower than the typical case (Jensen et al., 2015).

Discussion and conclusion

As seen in the cases analysed, the very stringent envelopes used in cold climates have a very relevant effect in the indoor temperatures, especially in the summer. This is due to the fact that they are optimised for heat conservation in the winter, but it has a similar effect in the summer, when we need to dispose of the unwanted heat. When adding the high internal gains that are typical of office buildings, as well as the long days and low angle of the sun characteristic of high latitudes, these tend to create overheating problems.

It is also interesting to see the effect of these two different approaches to a similar problem. In the Manitoba Hydro Place, the main element for environmental control consists of a series of buffer zones along the façades. These allow for a higher flexibility in the regulation of the indoor conditions prior the use of mechanical systems, with the pre-heating or pre-cooling of the incoming air. On the other hand, it has a very limited effect in the winter (+3°C temperature increase), unless it is combined with other heating systems. The summer temperatures obtained in the energy simulations also confirm the need for the combination of natural ventilation with evaporative cooling in the south atria for the pre-cooling of the incoming air.

On the other hand, the Powerhouse Kjørbo is a more typical case, relying on a highly insulated and airtight envelope, together with a very compact shape. This is reflected on an improved behaviour in the winter, with a temperature increase of almost 9°C. However, it also means that the unwanted heat produced or stored in the summer has it more difficult for escaping the building. This could cause severe overheating problems without environmental control systems, which supports the use of different passive strategies to avoid them.

Consequently, this research underlines the need for updating the existing methods for bioclimatic building design (BBCD), in order to consider the spontaneously generated microclimate, as a result of the use of stringent envelopes in combination with high internal gains in cold climates office buildings.

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Refurbishing Houses to Improve Energy Efficiency - Potential in Vietnam

Phan Anh Nguyen[1], Regina Bokel[1] and Andy van den Dobbelsteen[1]

[1] Department of Architectural Engineering and Technology, Faculty of Architecture and Built Environment, Delft University of Technology, Delft, Netherlands, p.a.nguyen@tudelft.nl

Abstract: The housing stock in Vietnam faces the challenge of becoming sustainable, provide a healthy living environment and reduce its energy consumption. The challenge lies not only in new buildings but also in existing houses. Nevertheless, little is known whether the new tube houses, the most dominant housing typology in Vietnam, can be renovated to offer adequate living conditions for the occupants, can tackle the issue of energy shortage, and can adapt to climate change. This paper introduces the potential of refurbishment design for energy efficiency. Although both passive and active approaches are encouraged, traditional bioclimatic design strategies, including solar control, natural ventilation and thermal insulation, are more popular because of their low cost and high efficiency. This paper concludes that solar energy has large potential in Vietnam because it can be used passively in sun space or actively in photovoltaics and solar thermal collectors. However, as these refurbishment measures require investments and careful design, the actual benefit in Vietnamese context has not yet been verified.

Keywords: refurbishment, energy efficiency, comfort, houses, Vietnam

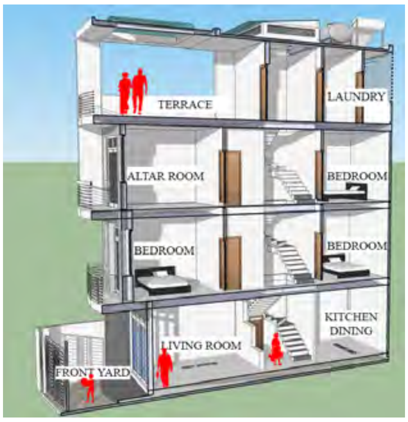
Introduction

Vietnam has undergone a lot of changes in its history. This includes different wars against Eastern and Western invaders as well as the development of a socialist society. As a result, Hanoi, the capital city of Vietnam, is therefore very rich in architectural styles and typologies which are reflected in its urban pattern. Most recently, the economic reform of 1986 called "Doi moi" has had a huge impact on the Vietnamese society. The rapid economic growth and privatisation of the market has resulted in the appearance and significant development of the "new tube house" which soon became the most dominant housing type in Vietnam. The spontaneous development of this housing type helped to solve the housing shortage in the context of urbanization and modernization. However, they also take major responsibility for a more sustainable housing stock in Vietnam.

The tube houses

New tube houses

A new tube house layout and spatial composition of a traditional one are presented in figure 1. A new tube house is normally built in a rectangular plot with the width of 3-6 meter and the depth of 10-20 meter; 3 to 5 storey high. Within this narrow plot of land, courtyard is often limited. The typical structure type is concrete frame and brick masonry.



New tube house Traditional tube house

Figure 1: Layout of a typical new tube house a traditional tube house in Vietnam

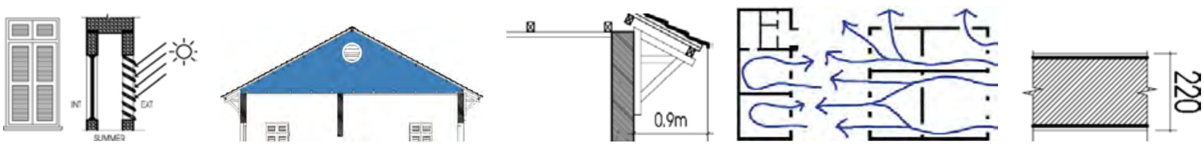
Several features of the traditional and new tube houses were compared as shown in table 1 (To, 2008). Traditional tube houses are more sustainable both in terms of spatial composition and climate responsive architecture elements.

Table 1: Comparison of the traditional tube houses and the new tube houses

	Traditional tube house	New tube house
Average plot size	3.5m x35m	4.5m x 20m
Inner courtyard	Yes	Limited
No. of storey	1-2	3-5
Building materials	Ceramic roof tiles, wood beams, brick walls, plaster	Reinforced concrete bearing frame, brick walls, plaster

Climate design in traditional tube houses

There are 3 main climatic regions in Vietnam from North to South, but there are some common climatic features that most houses have to deal with. Firstly, the high annual solar radiation result in great unwanted heat gains in building. Traditional tube houses applied double layer windows, with wooden shutter to block the direct sunlight and at the same time provide natural ventilation. The roofs are usually high and ventilated since the sun position is very high in the summer. Shading is provided by eaves and trees, while the later also benefit the houses with evaporative cooling. The houses were usually painted light colour to reflect the radiation. The high temperature and humidity make natural ventilation a mandatory design strategy in almost every house. Popular measures are high ceiling, large openings and the use of inner courtyard. Thermal mass is not applicable due to the low diurnal and seasonal temperature different. Most houses use local lightweight construction instead. Finally, most traditional houses have pitch roof because of the high annual rainfall. However, rain water harvesting is not yet considered though it has a huge potential to reuse this resource. Figure 2 below illustrates some of the bioclimatic techniques in traditional houses.



a b c d e

Figure 2: Some climatic design strategies in traditional houses of Vietnam

a. Double layer window b. ventilated roof c. deep eaves d. natural ventilation e. lightweight construction

Energy efficient design strategies

Both passive and active measures for refurbishment can reduce energy consumption in houses and provide better living conditions. Passive design, or similar strategies such as bioclimatic design or environmental design, uses architectural measures and considers the local climate, such as air and sun, in providing thermal and visual comfort without using additional energy. Active measures, on the other hand, consume a certain amount of auxiliary energy. This paper discusses both active and passive measures for Vietnamese context.

The Trias Energetica, introduced in the late 1980s (Lysen, 1996), lists sustainable measures for buildings according to their significance to sustainability. The concept includes three steps. The first step is to reduce energy by improving thermal performance, reducing heating and cooling loads. The next step involves generating and using renewable energy sources as much as possible. Finally, when non-renewable energy use is inevitable, this step consists of exploiting the non-renewable energy efficiently.

Introduced in 2002, Cradle to Cradle (C2C) is a new concept of sustainability (McDonough & Braungart, 2002). It focuses on closing material cycles and using waste as food for new lifecycles. Although the applications of this philosophy were mainly for materials and products, there are great opportunities that it can also be used for sustainable buildings and urban planning (Dobbelsteen, 2008).

Inspired by the C2C approach, Dobbelsteen (2008) proposed a new strategy with three main steps for sustainable building (figure 3). Basic idea is to create loop cycles of energy and material flows so that no waste is dumped in nature. The first step is similar to the first one of the Trias Energetica, reducing energy demand. It is the most important step in all strategies and is often referred as passive design or bioclimatic design. The next steps, inspired by C2C, are to recycle the waste flows both internally and externally. The final step is to supply the house with sustainable energy sources and let waste be food. In terms of energy efficiency, these new strategy steps consider the use of waste energy in the cycles of energy, materials and water.

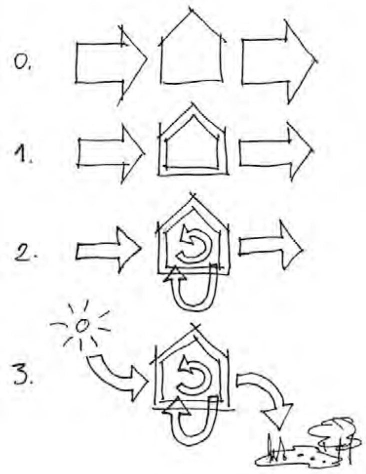


Figure 3: The New Stepped Strategy: 1. reduce the demand, 2. reuse and recycle, 3a. supply the resulting demand sustainably and 3b. let waste be food.(Dobbelsteen, 2008)

In Vietnam, the National Technical Regulation on Energy Efficiency Buildings (NTREEB) provides mandatory technical standards to achieve energy efficiency in the design, new construction or retrofit of civil buildings (MOC, 2013). These standards apply to 6 categories, i.e. building envelope, ventilation and air-conditioning, water heating, interior lighting, and auxiliary energy. These standards cover both active and passive measures and also align with the Trias Energetica. Table 2 below summarizes potential design measures for refurbishing new tube houses. Application of these design strategies in Vietnam context will be discussed in the following parts of this paper.

Table 2: Potential refurbishment design strategies for housing in Vietnam

Design strategies	**Detail measure**	**Potential**	**Involving Building Element**
Solar control	Orientation, massing Natural control (trees)	Limited	
	Shading devices	High	Opaque envelope
Natural ventilation	Cross ventilation	High	Windows Internal dividing
	Stack effect	Low	Inner courtyard
Evaporative cooling (EC)	Direct EC (trees, pond)	Moderate	Courtyard Envelope
	Indirect EC	Limited	Envelope
Passive solar gain	Direct gain (windows, envelope)	High	South Façade
	Indirect gain (sun space)	Limited	South Façade
Thermal mass	High thermal mass walls	Limited	Building envelope
Daylight	Side Windows Light well/ Courtyard	High	Windows Courtyard
Thermal Insulation	Highly insulated envelope	High	Roof
Solar energy	Photovoltaics (PV cells)	Moderate	Roof
	Solar collectors	High	Roof
Biomass	Algae/Bio waste	Limited	
Active heating/cooling	Ground source heat pump	Limited	Underground
	Air source heat pump	Moderate	Wall
Lighting and appliances	Energy efficiency equipment Automation system	High	Equipment

Passive design strategy

Avoid overheating

Located in a subtropical climate region, the main climate characteristics of Vietnam are a high annual temperature and high solar radiation. Therefore, overheating becomes the biggest problem in houses that passive design needs to deal with. There are several techniques that are used to prevent this phenomenon, such as solar control, natural ventilation and green building envelope. In order to achieve highly efficient cooling in a building, generally more than one system is applied.

Solar control (orientation/ shading device)

In Vietnam, the most preferable orientation is south and south west because it helps to catch the prevailing cool winds and easily avoid direct solar gain. High solar radiation and the low sun position make the west the least favourable orientation. However, for tube houses, where orientation options are limited, this principle only applies when the house has more than one façade. In refurbishment projects, changing orientation is usually not possible.

When the house has an unfavourable orientation, for example west, an additional shading solution can control the solar access. Firstly, shading can be achieved through architectural massing. A service space that does not require high thermal comfort can be used as a protective layer for the internal living space from the heat gain. This measure requires intensive refurbishing, usually when extra space is needed. Natural elements such as trees or shrubs can shade the building from sunlight and provide additional evaporative cooling of both indoor and outdoor environments (McGregor & Trulsson, 2001). As tube houses usually are built on the whole plot, there is lack of space to allocate additional trees in an existing project. Green facade, however, is an alternative. Finally, a shading device is the most efficient element to block solar radiation. Apart from being more efficient, external shading devices are easier to retrofit than an internal one (Almusaed, 2011).

Natural ventilation

Natural ventilation is the most popular and most important measure to deal with overheating in the hot and humid climate. First, it helps cool the human body by the effect of evaporation of sweat and by convection. In this case, the air speed needs to be at least 0.2 m/s for the cooling to be effective (A. T. Nguyen, 2013). Furthermore, building structures with high thermal mass, heated during daytime, can be cooled down using night ventilation provided that the temperature at night is within or below comfort zone. Finally, it helps prevent condensation in the high humidity environment.

Natural ventilation can be classified as three main types: cross ventilation, single side ventilation and stack ventilation (CIBSE, 1997). In Vietnam, stack ventilation is not efficient due to the small different temperature between indoor and outdoor temperature. Therefore, wind-driven ventilation is the main ventilation strategy (A. T. Nguyen, 2013).

In Vietnam, there are different kinds of monsoon winds. Good understanding of the monsoon wind can help supply the buildings with a fresh cool breeze in summer as well as avoid cold winds in winter. However, natural ventilation requires good control of air quality. In big cities, for example Hanoi or Ho Chi Minh City, sometimes air quality is very poor. The air quality index of these places can sometimes be very high, and there are dust and pollutants in the air. Therefore, no matter the ventilation system, there should be always an option to control the amount of air allowed into the buildings. Filtering layers such as greenery systems are recommended.

Evaporative cooling

Evaporative cooling is not efficient in hot and humid climate area because high humidity level increases thermal discomfort (Almusaed, 2011).

Passive solar use

In winter time, where the outdoor temperature can drop to a very low level, heating is needed to ensure a comfortable living space for occupants. The heating season occurs in the northern parts of Vietnam which are affected by the cold monsoon wind. The winter climate of northern Vietnam is not that severe compared to the winter in temperate climates as in the Netherlands. However, traditional Vietnamese architecture tends to mainly solve the problem of hot summers, maximizing opening, using lightweight structures. Therefore, the indoor temperature in wintertime can be very cold and require a lot of heating.

Passive solar strategies are widely used in the temperate climate, making use of the energy from the solar radiation to heat the internal space without mechanic equipment. Solar gains can be achieved directly (through glazed area) or indirectly (sunspace and thermal mass). Passive solar gains are mainly achieved on the south façade of a building (or north façade if the house is in the southern hemisphere). It is also a limitation of this strategy. Passive solar design is not feasible if the house is shaded by other buildings or trees, or, in case of the tube house, if the south façade is not available.

Sunspace
One main advantage of a sunspace is that it provides occupants with extra living space. However, it also has some shortcomings. Firstly, a sunspace might lead to extreme overheating in summertime, especially in a hot climate of Vietnam. The glazed parts need to be openable and be protected by shading devices. In that case, a sunspace works as a terraced area or a veranda. Moreover, sunspace is usually considered less efficient as it saves less energy in comparison with its cost. In refurbishment of a tube house, an additional sunspace is not always available if the house uses all the space of its plot.

Thermal mass
In climates that are constantly hot or cold, the thermal mass effect can actually be detrimental. All surfaces of the mass will tend towards the average daily temperature; if this temperature is above or below the comfortable range, it will result in even more occupant discomfort due to unwanted radiant gains or losses. Therefore, in warm tropical and equatorial climates buildings tend to be very open and lightweight.

Heat Protection

Thermal Insulation
In the Vietnam summer time, it is essential to protect the building from heat gains. High sun angles make the roof to be the most important element to be protected from radiative heat gains. Insulation on the roof is usually done with a layer of low emissivity material and a ventilated cavity. A bright colour paint can help the walls to reduce heat gains from radiation. However, because of the high humidity, natural ventilation is encouraged and windows are usually open. The small difference in temperature between the outdoor and indoor space makes the resistance to heat conduction less significant.

Air-tightness
The winter of Vietnam is not so harsh compared to countries in a temperate climate. However, existing housing is facing problems of air leakage or infiltration. Together with a poor insulated opaque envelope, it makes the heating demand becomes much higher.

Active design strategy

Renewable energy sources
Utilising renewable energy sources is an important step in both the Trias Energetica and C2C-inspired approach. Such power sources come from the sun (photovoltaic, solar collector), the wind (wind turbine), the earth (geothermal energy) or biomass.

Photovoltaic (PV) energy
Vietnam has a constant solar energy source. In the North, solar radiation intensity ranges from 2.4 to 5.6 kWh/m2/day while in the Central and the South, energy from solar irradiance varies is distributed uniformly from 4 to 5.9 kWh/m2/day (N. T. Nguyen & Ha-Duong, 2009). However, efficiency of PV systems in the tropical climates is not necessarily better than that in the temperate climate. This is mainly due to the fact that PV cells efficiency largely depends on the cell surface temperature. The higher the temperature, the lower the efficiency (Bahaidarah et al, 2013). The main solution to this problem is to cool the cells by using water or air on top or under the cells surface.

Solar thermal systems
Solar thermal systems are quite popular in Vietnam because of its easy installation, low cost and availability of solar radiation. Installation of solar collectors and water tanks is easy. However, in refurbishment projects, it is often required to also replace the plumbing system because traditional ones were not designed for hot water and such replacement is usually more complex. It could be a good solution when the owner wants to replace the service system in the house after a long time use.

Biomass
Biomass systems often require a specific area to burn the fuel to generate heat. Therefore, this energy source is more popular in rural areas than in high density urban area of Vietnam.

Active cooling/heating

Air source heat pump
Contemporary Vietnamese houses often do not employ enough natural ventilation due to the limited design parameters. Furthermore, the outdoor temperature is not always healthy. Therefore, air-conditioning systems are widely used in Vietnam to introduce fresh air with an appropriate temperature, ensuring indoor air quality. However, they often consume too much energy and thus increase the environmental impact of the buildings.

Ground source heat pump (GSHP)
In climates with high average air temperature levels and little temperature fluctuations, the application of geothermal energy is very limited (Eicker, 2014). Furthermore, geothermal heat pumps are usually incorporated into new buildings projects and are not suitable for refurbishment project because their installation involves digging into the ground and the cost is usually quite high. Therefore, GSHP is not applicable in housing refurbishment in Vietnam.

Efficient use of non-renewable sources

Heating and cooling
In Vietnam, where both heating and cooling are required, air-conditioner often carries both duties in one single system. Efficiency of the air-conditioning system can be improved by increasing insulation for the pipes system. It is also important to keep indoor air temperature cool as long as possible. Therefore, reducing heat transfer through building envelope also help reduce energy consumption of the air-conditioner (Konstantinou, 2014). The Vietnamese National Building Code of Energy Efficiency Buildings set out certain requirements for air-conditioning system (MOC, 2013).

Lighting and appliances
In Vietnam, electrical appliances and lighting accounted for 11% and 8% energy use in residential building respectively (MOC, 2013). Improving energy efficiency of such equipment during refurbishment can contribute to the total energy saving of the houses. To reduce the energy consumption of this part, low energy efficient products should be replaced. Furthermore, the government also issues a regulation framework for the energy labelling program and directives for implementation (DECISION, 2011). Energy efficiency of appliances can also be improved by using smart control system with human sensors and automatic programming function.

CONCLUSION

In Vietnam, popular passive design strategies include solar control, natural ventilation and evaporative cooling. However, tube houses constraints limit the effectiveness of passive design measures. For example, orientation is generally not changeable. Small land plots and high demands of living spaces do not allow many options for massing and courtyard although a courtyard is a very important feature of a traditional tube house. Thermal insulation layers are mostly found on the roof. Air-tightness can efficiently prevent the houses from losing heat in winter. Passive solar gain might work for the cold winter of Vietnam directly or indirectly (sun space). Geothermal cooling and thermal mass are not recommended for renovating houses in Vietnam.

Active design strategies are generally not popular in Vietnam yet. Although the country has a high annual solar radiation, solar energy is mostly captured by solar collectors that provide hot domestic water. This system is easy to install and has high efficiency. Solar photovoltaics have not been applied widely because they are often – wrongly, considering the recent price of PV - considered not cost effective compared to the traditional fossil sources and they are mostly used for off-grid areas. Biomass is another clean energy source that can be used for homes. But it is not suitable for urban housing since it takes up spaces for burning and might harm air quality and human health. Using highly efficient equipment and lighting appliances can potentially reduce energy consumption in housing. To promote using energy-efficient equipment, it requires the commitment of the government, manufacturer and potential users.

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The Influence of Courtyards' Microclimate Condition on The Users' Spatial Behaviour: A Case Study in A University Campus in Hot Dry Regions

Bushra Obeidat[1], Mohammed Alshayeb[1], and Afnan Barri[1]

[1] Department of Architecture, School of Architecture, design and Planning, The University of Kansas, Lawrence, Kansas, USA.

Abstract: Courtyards are essential architectural elements that form places for gatherings and are designed based on climatic considerations. This study aims to investigate the impacts of three simulated thermal variables on students' spatial distribution in university courtyard sittings. Spatial distribution, in our case, is understood as the location of different users in the courtyard space in consideration to their static activities; sitting and standing. Field observations and three computer simulation studies were used to investigate these effects in two similar courtyards. Simulation studies include (1) a microclimate air temperature analysis, (2) an intensity of direct solar radiation analysis, and (3) a shadow analysis of the number of sunlight hours received in the courtyard. Statistical correlation analysis demonstrates that climatic and thermal variables can impact the spatial distribution of students within the courtyards. This research provides a basis for research-based design of outdoor shared spaces; Its methodology extends the use of simulations software beyond research about microclimate data, connecting it to the study of human behaviour. Architects and designer can benefit from this research to define design variants that influences environmental and behavioural performances of courtyards in hot dry regions.

Keywords: Courtyard design, Students' distribution, Simulation, Microclimate, Grasshopper

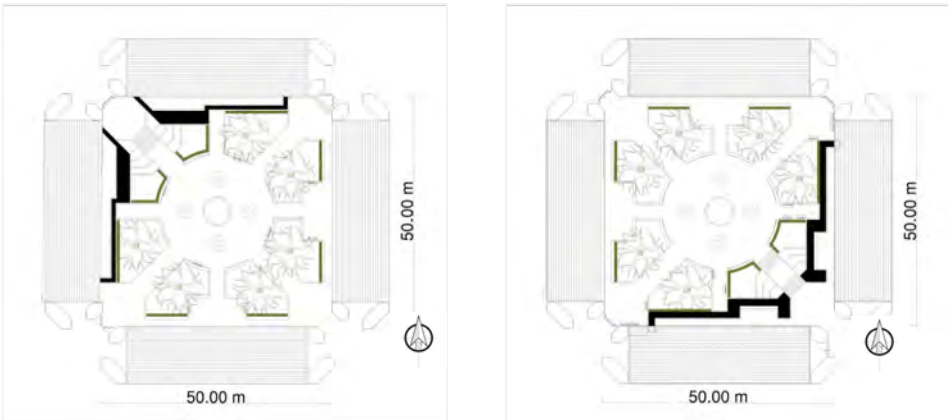
Background Information

Previous environmental-behaviour studies reported the impact of spaces' physical and spatial features on students' behaviours in campus outdoor spaces, such as location, accessibility, seating spaces, and visual qualities (Abu-Ghazzeh, 1999, Aydin and Ter, 2008). Additionally, natural elements, such as trees and plants were discussed as factors that can influence behavioural patterns in outdoor settings (Salama, 2008, Ünlü et al., 2009). However, in designing outdoor environments, literature indicated the significance of understanding the microclimate conditions of a certain environment in determining the design of outdoor spaces (Almhafdy et al., 2013, Nikolopoulou et al., 2001). Therefore, the focus of this study is to investigate the effect of microclimates on students' spatial behaviour and distribution. Two methods of data collection were used for this investigation: behavioural mapping and thermal simulation.

Behavioural mapping is a technique that was developed by Ittelson (1970) to identify patterns and frequencies of human behaviour in a space and map these data on that space layout. The methodology involves dividing the map of the environment into zones and then recording patterns of behaviour across each zone. Whyte (1980) and Marcus and Francis (1998)applied this method to investigate the impact of physical characteristics of places in relation to the users' sitting behaviour. Similarly, Gehl (2011) used behaviour mapping to address the impact of spatial definition elements, such as walls to attract people into a space.

Thermal simulations are a set of computer programs developed to simulate the thermal performance of places depending on their climatic information. Based on these simulation, many variables can be derived and can be used as a predictive tool for optimizing space layout and its proper dimensions to improve thermal comfort of occupants. Rhinoceros with its graphical algorithm editor Grasshopper was used to conduct dynamic simulations and evaluate individual metrics of environmental information, such as solar intensity, air-temperature, wind speed, and other climatic data.

This study was carried out using these two techniques, behavioural mapping and thermal simulation, to investigate students' patterns of behaviour in two identical courtyards at the Jordan University of Science and Technology. The courtyards (A) and (B) have a rectangular open form with an area of 2500 m2. As Figure (1) illustrates, the courtyard space consists of grass surfaces, trees, seating spaces, and a centralized fountain. The university buildings surround the courtyards from their four sides. The two courtyards (A) and (B) differ in their orientation, where the elements of the courtyard (A) are at opposite locations of the other courtyard (B).



A. Courtyard B. Courtyard

Figure 1: Courtyards Under Investigation

Methodology

The research methodology includes simulations of climatic qualities of the courtyards, onsite observation study, and statistical analysis. During the on-site observation, the researcher collected both students' situations and basic climatic information, which was then used to develop the baseline model for the computer simulation work. The dependent variables of the model are the number of students who are occupying the spaces and their static spatial behaviours. The independent variables are microclimate temperatures measured in Celsius degrees, solar radiation measured in kWh/m2, and sunlight hours measured in hours. The steps of the research are described in Figure (2) below.

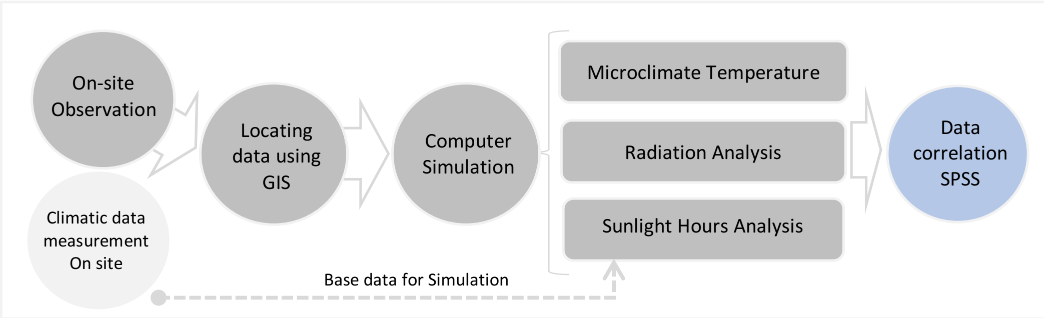


Figure 2: Research Process

On-site Observation

In Jordan, June is recognized as a month with high air temperature values and solar intensity. Hence, the site observations were conducted during five days in summer solstice of June 20th to June 25th. 2015. During each day, observations were carried out from 8:00am to 2:00pm within a regular interval of 30 minutes. Students' locations and their sitting and standing situations were recorded on the plan of each courtyard (Figure.3). The collected data was compiled using GIS for further analysis. Overall, 12 rounds of observations were completed in each courtyard, and 3867 of students' conditions and locations were identified during the observation period. Among them, 1489 students were male students, and 2378 were female students. The courtyards were divided into four parts in order to record patterns of behaviour across each zone in detail.

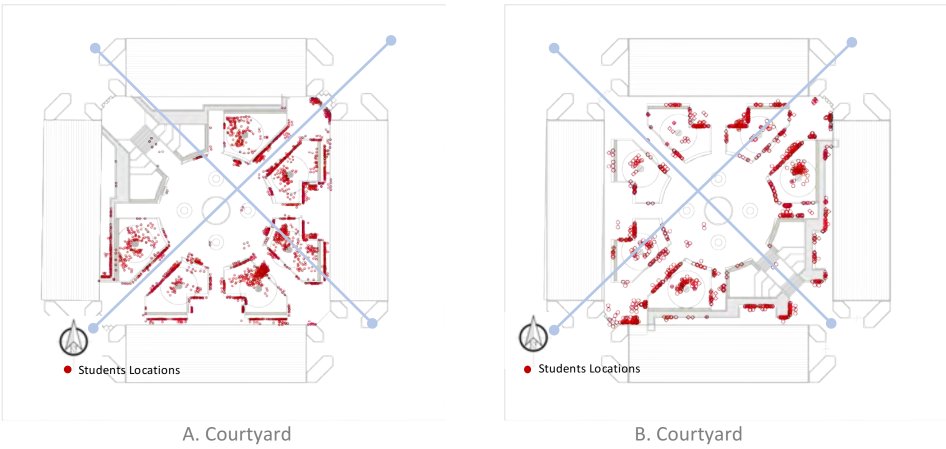


Figure 3: Recording Students' Behaviour and Position during Observations

Computer Simulation

Site observation was the first process of developing the baseline model for the computational experiment. In order to investigate students' situations based on the thermal conditions of the case study courtyards, a model was built using Grasshopper software. Grasshopper in Rhinoceros is a complete environmental analysis tool that covers the broad range of simulation and analysis functions (Rutten, 2012). In this research three types of simulations were conducted: microclimatic map analysis, radiation analysis, and sunlight hours' analysis as shown in Figure (4) below.

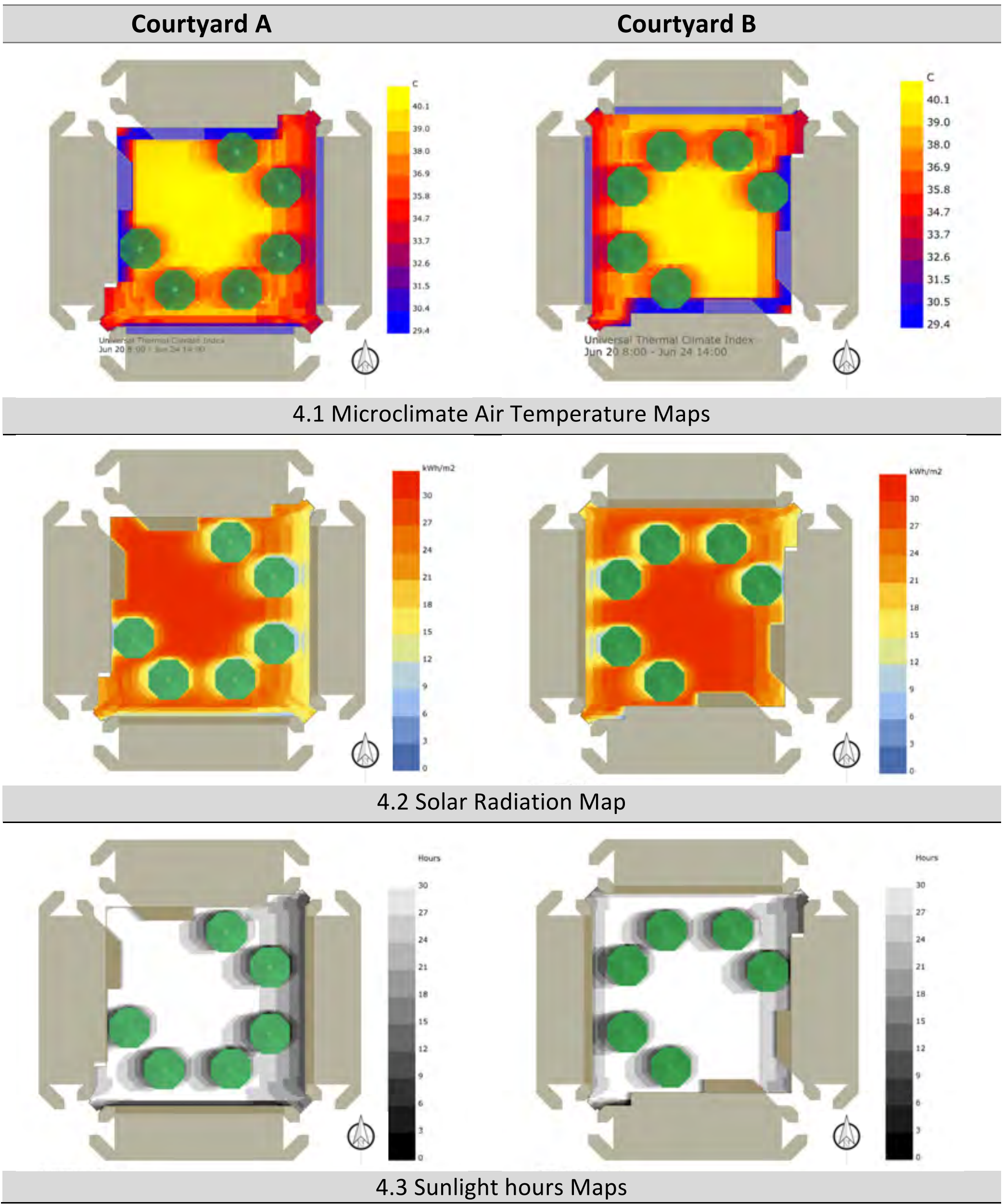


Figure 4: Three Thermal Studies using Grasshopper in Rhinoceros

Statistical Analysis

Using IBM SPSS 22 (SPSS, 2013), correlation analyses were performed to describe relationships between different climatic and thermal variables and students' numbers and their static behaviours. Statistical study tested the following two hypotheses with *gender* as a moderating variable:

- Hypothesis-1: Different thermal variables of campus courtyards would show different but consistent relationships with students' aggregate numbers.
- Hypothesis-2: Different thermal variables of campus courtyards would show different but consistent relationships with students' static activity positions (sittings, and standings).

The Aggregate Number of Students

The correlation coefficients in Table (1) illustrate a strong negative correlation between the number of students existing in the courtyard and the thermal variables; average air temperature, solar radiation, and sunlight hours recorded in the courtyards (Pearson r = -0.787, -0.726, and -0.739 respectively). Any increase in air temperature, solar radiation, and the number of sunlight hours in the courtyards will decrease the number of students' occupying the courtyards. The analysis showed strong negative correlations between the total number of male students in the courtyard and average air temperature and sunlight hours (Pearson r = - 0.814, and -0.712 respectively). The correlation coefficients show strong negative correlations between the courtyard average air temperature, solar radiation, and average sunlight hours and the number of female students who use the courtyards. The statistical analysis noticeably showed an increase in courtyards' temperature would negatively impact the number of female students using the courtyard.

Supporting Hypothesis-1, different courtyards' microclimate and thermal features show different relationships with the number of male and female students who are using the courtyards. Microclimate air temperature variable show stronger effects on students' numbers comparing with other two variables; solar radiation and sunlight hours.

Table 1: Correlation between the numbers of students and thermal variables

	Microclimate Temperature	Solar Radiation	Sunlight Hours
Students' Total	-0.787*	-0.726*	-0.739*
Male Students	-0.814*	-0.674	-0.712*
Female Students	-0.739*	-0.720*	-0.721*

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

Static Activities (sittings, and standings)

The correlation coefficients in Table (2) show a strong negative correlation between the average microclimate temperature, sunlight hours recorded in the courtyard, and the total number of students' who are in sitting positions in the courtyards (Pearson r = -0.768 and -0.721). The number of female students who are In sitting positions in the courtyards is more influenced more by courtyards' microclimate and thermal status than the number of male students. Similarly, the number of female students who are in standing positions in the courtyards is more correlated with the thermal variables than the number of male students who are in standing positions. These results indicated that thermal variables show stronger effects on female students' than male students' static behaviours.

Partially supporting Hypothesis-2, different courtyards' microclimate and thermal features show different relationships with the number of male and female students who are in sitting and standing positions in the courtyards, with microclimate temperature values having the strongest relationships.

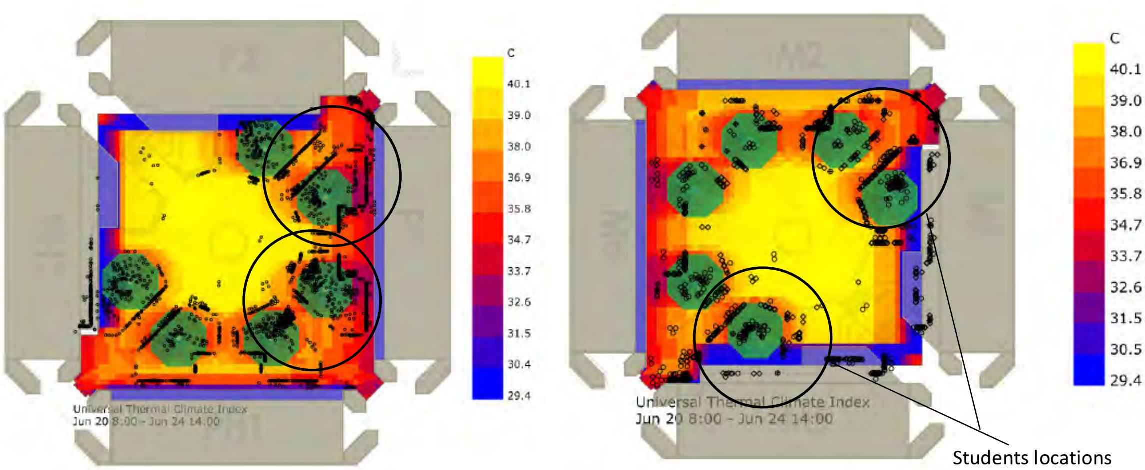
Table 2: Correlations between the numbers of students in static positions and thermal variables

		Microclimate Temperature	Solar Radiation	Sunlight Hours
Sitting	_ Students total	-0.769*	-0.700	-0.721*
	_ Male	-0.725*	-0.577	-0.637
	_ Female	-0.743*	-.717*	-0.718*
Standing	_ Students total	-0.277	-0.139	-0.264
	_ Male	0.010	0.155	0.037
	_ Female	-0.697	-0.736*	-0.734*

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

Mapping students' locations on microclimate air temperature maps

Statistical correlation analysis showed that the number of students occupying the courtyards are influenced by the average microclimate air temperature recorded in the courtyards. Mapping students' locations on microclimate air temperature map show that students mostly sit and stand in spaces with lower temperature. These spaces as shown in Figure (5) are either spaces close to the surrounding buildings of the courtyards or spaces close to grass surfaces and trees. The surrounding buildings provided shaded spaces that have lower temperature and cooling the ground surfaces. Similarly, the presence of grass surfaces contributes to the reduction of microclimate temperature of the courtyards. Therefore, more number of students are attracted and use these green spaces.



A. Courtyard B. Courtyard

Figure 5: Mapping Students' locations on microclimate air temperature maps.

Discussion and Conclusions

Studies have identified some critical design elements that affect the way that people use public spaces. There are several physical, climatic, and cultural factors impacting the usage of the outdoor spaces. The design of outdoor social spaces literature identifies the importance of understanding the space microclimate performance and designing around it. This research is a first step toward answering that call. This research used field observation and computer simulations to investigate the relationship between the space usage and its microclimate. Statistical analysis results verified that the courtyard microclimate performance impacts the number and distribution of students who occupied the courtyard spaces. The study indicated that air temperature values are more correlated with the number of students than other values; and that male and female students are affected differently by different climatic and thermal features. Female sitting and standing positions in the courtyard were influenced by thermal climatic and thermal features more than male students. In order to design courtyard's spaces in hot arid regions like Jordan, it is important to provide more shaded and green spaces. These two strategies will lower the microclimate air temperature in outdoor spaces.

The study concludes that despite the differences in the courtyards orientations, there is no significant difference in students' behaviours in response to courtyards' climatic features. Generating Air temperature, radiation, and sunlight hours' maps using Grasshopper can help campus designers to understand the environmental performance of their outdoor spaces designs and make design decisions regarding users' distribution at early stages of the design process. The findings of this research contribute to the design of campuses outdoor spaces in hot dry regions.

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Design to Thrive

Architectural Passive Solar Design for Three Buildings in Kenya: Observations Made in Lowering Energy Use in Non-domestic Buildings

David Mwale Ogoli

Judson University, Department of Architecture & Interior Design
1151 North State Street IL 60123 (USA)

Abstract: This paper discusses design, construction & operation of sustainable buildings in the climate of Nairobi, Kenya. Local conditions were given in monthly psychrometrics. Firstly, Nairobi is about 1798 m (5900 feet) in altitude. The local climate has 215 heating degree days base 65° F (18.3° C), and 480 cooling degree days base 65° F (18.3° C), a ratio of approximately 1:2. Secondly, three buildings were compared for green building design. They were constructed with materials indigenous to equatorial highlands of Kenya. Thirdly, the paper provided some drawings to illustrate passive solar design strategies for architectural composition: form, shape, geometry, and building spatial proportions. Comfort in buildings is dependent on the adaptive strategies, behavioural actions and clothing levels of occupants of a building in a given climatic environment. Some adaptive strategies for thermal comfort (changing clothing levels, activity, posture, location within a space, opening a window, complaining and/or leaving a space) have profound architectural implications. The American Society of Heating Refrigerating and Air-conditioning Engineers *ASHRAE Green Guide* was referenced for design techniques. It is this bringing together of physical factors of the environment and adaptive factors (clothing, activity, posture) that allows participants to truly experience comfort in architecture in Kenya.

Keywords: Climate, comfort, thermal mass and energy

Introduction

Kenya has a wide range of climatic conditions that have uniquely differing characteristics. The equator bisects the country at almost its mid-point and there is a predominant need for cooling which puts a major requirement on building characteristics, i. e. materials, form, siting and planning, to assist in achieving this objective of cooling by natural means. Problems of design are generally associated with outdoor air temperature, solar radiation and, air infiltration of warm outside air into the building. A thorough knowledge and understanding of the climate of Kenya has been made before analysing the role of thermal mass.

Passive and Low Energy is a topic that has received theoretical and practical attention during the past several years and there now exists ample research information in temperate climates. Urban areas in Kenya are rapidly growing in population and size with non-domestic buildings coming up in different sizes and shapes. Many of them are conceived are designed with air conditioning as part of the "design brief". The large amounts of energy needed by such buildings has prompted many designers to seriously re-think the passive cooling option. In Kenya, electricity is a very expensive commodity and conserving it is advisable. By passive cooling design attention is drawn to those attempts of using the building's fabric to control external solar gains and provide the much needed time-lag in high daytime temperatures so that they appear much later after office hours or at night. The presumption is that night-time ventilation will provide adequate cooling to the thermal mass.

ASHRAE Design techniques

Sustainability has been a matter of concern locally and globally for both public and private sectors. The American Society of Heating Refrigerating and Air-conditioning Engineers (ASHRAE) has *ASHRAE Green Guide* aimed at improving the impact of buildings on the environment. It defines sustainability as "providing for the needs of the present without detracting from the ability to fulfil the needs of the future" (ASHRAE, 2017:35.1). ASHRAE differentiates sustainable design from green design by stating that although these two are similar green design focuses on the near-term impacts of indoor air quality, operation and maintenance. Sustainable design on the other hand addresses the future long-term global impact caused by buildings. It therefore goes beyond just keeping data on "energy usage, carbon emissions, pollution, waste disposal, or population growth" (ASHRAE, 2017:35.1). It is the full stock of buildings and other elements in the society that will comprehensively develop a good sustainable design. The observance of these three buildings in diverse climatic conditions may provide insight for other similar regions in Africa, and probably elsewhere also.

The *ASHRAE Green Guide* suggests that the building energy use elements for effective impact in sustainable design are (1) envelope, (2) lighting and (3) other loads) ASHRAE 2017:35.10-11). Use of night-cooled thermal mass, insulation, operable windows, control of solar gains, natural daylighting, and overall heating, ventilating and air conditioning (HVAC) systems were considered and adapted in the following experimental house types in Kenya.

Experimental Method

Three similar buildings were simulated in three climatic equatorial zones of Kenya: highland (Eldoret), mid-highland (Nairobi) and lowland (Mombasa). These three regions represent conditions that vary from cool temperate-like areas to hot humid conditions at sea level. This paper gives a brief introduction to the problem, describes the climatic conditions in the different zones and their impact on building design. It provides architectural strategies of prevention and modulation of thermal gains by controlling solar gains and external gains, with a specific look at those climatic zones, with specific reference to the role of thermal mass in achieving passive cooling. Thermal simulations were conducted using Autodesk REVIT.

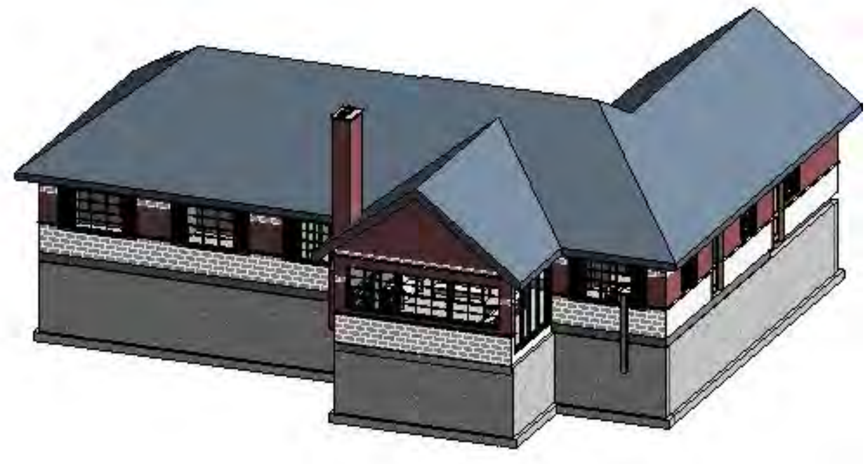

Figure 1. Test building with high thermal mass used in the simulations

The test building measured 20.0 x12.0 metres. See figure 1. Other design considerations:

1. One wall was north facing, insulated externally, and has variable thermal mass. Values ranging from light-weight to heavy-weight that were tested were:- 12mm, 25mm, 50mm, 100mm, 200mm, 300mm and 400mm.
2. Two walls were east-west facing, insulated externally, and have variable thermal mass. Values to be tested were:- 12mm, 25mm, 50mm, 100mm, 200mm, 300mm and 400mm.
3. One wall was an internal partition with variable thermal mass. Its value was kept constant when that of the external walls is being varied, and vice versa it was varied when that of external walls was kept constant. Values to be tested were:- 12mm, 25mm, 50mm, 100mm, 200mm, 300mm and 400mm. Finally from the results, an ordinary acoustic partition was used as described in Fig. 18
4. One wall, corridor, floor and ceiling were assumed to be having no heat gains/losses i.e. the temperature difference between the adjacent spaces and the room being examined will be same.
5. All other factors, such as volume-to-surface ratio, etc., etc., were kept constant.

NOTE: walls measuring 12mm, 25mm and 50mm, had not been simulated initially until after the results of the larger masses. These are taken as being equivalent to less dense materials. Lord Kelvin (1824-1907) said: “When you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the stage of science, whatever the matter may be”. This paper is a discussion of practical observable occurrences of three similar house design in three equatorial areas in Kenya.

Observations

Climate of Kenya

In Kenya, lowland areas are very hot and tend to have poor rainfall and a dry atmosphere with low humidity. The main exemption is the coastal strip and the area along the shores of Lake Victoria which are hot with high rainfall and high humidity. Snow is found daily on the peak of Mount Kenya all year round and conditions at such altitudes are typical of cool temperate winters (Figure 2).

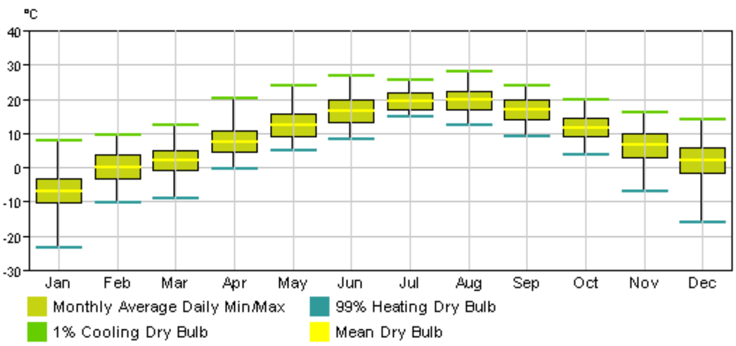

Figure 2. Monthly dry-bulb temperatures

At lower altitudes, high temperatures exists. Temperature falls as altitude rises using the following relationship between altitude (A) above sea level and mean air temperature (T_{Mean}) (Ogoli, 2000:827-828):

$$T_{Mean}) \text{ (°C)} = 28.7 - 0.00590A_{metres} \text{ (SI system)}$$

T_{Mean}) (°F) = 83.7 – 0.00324A_{feet} (IP system)

Annually, Nairobi requires cooling 6% of the year, heating 60% of the year and it is within the comfort zone 34% of the year. An equatorial region has high solar radiation yet, as a recent study shows, air temperature drops with altitude at a rate of approximately 5.9ºC every 1000-metre rise (approximately 3.24ºF every 1000-foot rise). Table 2 shows observed outdoor weather data.

Table 1. Observed outdoor weather data

	Heating Dry-bulb temperature (°C)		Cooling Dry-bulb (DB) temperature and mean coincident wet-bulb (MCWB) temperature (°F)						Heating degree days	Cooling degree days
			0.4%		1.0%		2.0%			
	99.60%	99%	DB	MCWB	DB	MCWB	DB	MCWB	HDD18.3	CDD18.3
Mombasa	19.9	20.8	33.1	25.2	32.5	25.1	32.1	25.0	0	2982
Nairobi JKIA	9.9	11.1	29.0	15.7	28.1	15.8	27.3	16.0	98	551
	Heating Dry-bulb temperature (°C)		Cooling Dry-bulb (DB) temperature and mean coincident wet-bulb (MCWB) temperature (°F)						Heating degree days	Cooling degree days
			0.4%		1.0%		2.0%			
	99.60%	99%	DB	MCWB	DB	MCWB	DB	MCWB	HDD65	CDD65
Mombasa	67.9	69.4	91.5	77.4	90.5	77.2	89.7	77	0	5367
Nairobi JKIA	49.8	51.9	84.2	60.3	82.6	60.4	81.1	60.8	177	993

Topography

A typical section showing the topography of Kenya is summarized in Figure 2. Mombasa is at sea level. The highest point is Mt Kenya at an altitude of 5199m (17058 feet) above sea level. The rift valley is a major feature occurring in the central highlands. The ensuing climatic zones are affected by this topographical layout. Kenya experiences strong seasonal winds that are responsible for the rainy seasons. Most people live at altitudes between 1000 and 2500m (3048 and 8202 feet) above sea level.

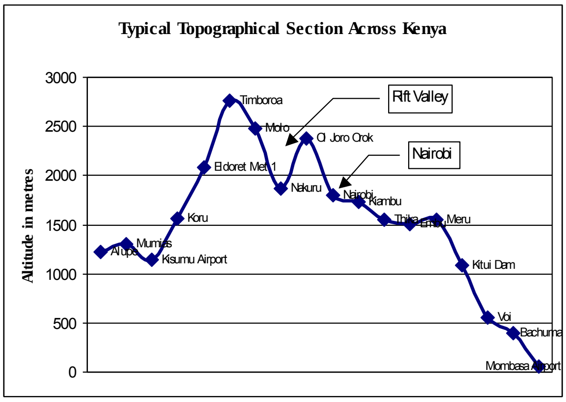

Figure 3. Topographical section across Kenya

Analysis and Discussion

Impact of climate on design

Air temperature

For much of the day and year outdoor air temperatures in the different climatic zones of Kenya are well outside the comfort limits. A major function of non-domestic buildings is therefore to modify and regulate outdoor air temperatures so that the temperatures indoors may be within comfort limits. The structure of the building itself offers an important means of thermal control. Choosing wall and roof materials that have a high thermal capacity and/or high thermal insulation value can give the required modification. Local materials with a high insulation value such as Makuti[1] and expanded polystyrene have a low rate of conductivity while elements made of high capacity materials such as locally available stone are able to store up large amounts of heat without greatly raising the temperatures of their internal surfaces. The peak temperature delay they create, termed time-lag, is essential in the balancing of time. Heavy structures of high thermal capacities have a dampening effect on the daily temperatures and hence balance-off the "time".

Floor temperatures remained consistently within the comfort zone except for a few times when there was an overheated point late in the afternoon hours. The observable point in the graphs is that the higher the thermal mass, the more the moderating effect on indoor maximum temperatures. As expected, temperatures were stratified in the room; cooler at the lower levels and hotter at higher levels. The low mass buildings closely followed outdoor conditions and did not offer much thermal storage. In one case when maximum outdoor temperature was over 33ºC (91ºF), the indoor maximum temperature in high mass building was 25.4ºC (77.7ºF), which is within the comfort zone. The humidity levels appear to be similar throughout the test period. The highest humidity is at dawn when air temperature is least; humidity is least in the early afternoon when air temperature is highest (Figure 4).

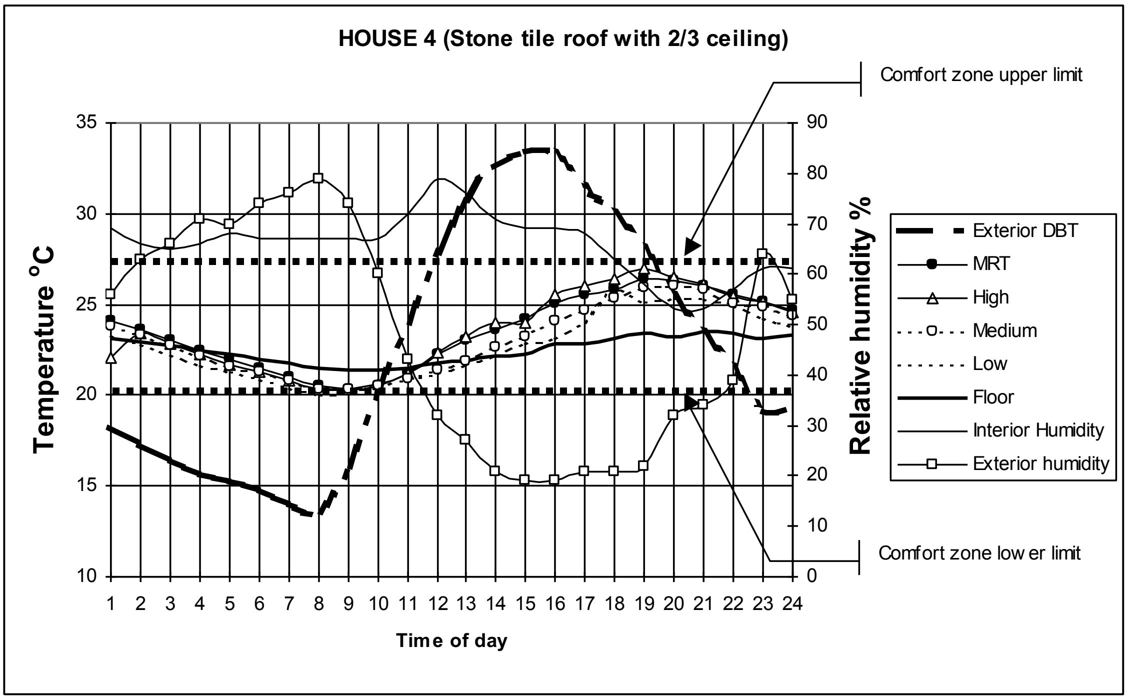

Figure 4. Observations in House 4 with high thermal mass

Sunshine and radiation

Radiation on external surfaces of walls and roofs can raise temperatures well above that of the ambient air; dark coloured surfaces absorb more heat than light coloured surfaces. When dark elements are used in direct contact with solar radiation the heat they absorb is conducted to the inner faces of walls and roofs which then become heat radiators. This raises indoor temperatures. Glazed elements are largely transparent to solar radiation. When heat is re-emitted by internal surfaces where direct sunlight is incident, it is long wave radiation

[1] Makuti is the local Swahili name for coconut palm tree leaves. It is used as a roofing material.

[low temperature]. It cannot escape to the outside since this type of radiation is blocked by glazing as glass is opaque to energy emitted from low temperature sources, and hence a green-house effect. Horizontal roof surfaces receive the greatest quantities of radiation followed by east and west walls. North and south walls receive the least intensities. Greater solar heat gains are experienced on west walls than east walls as there is more cloud cover in the morning than in the afternoon, and on south more than north walls as there is greater cloudiness during the months when the sun is north of equator [April to September] than during the months when the sun is south of the equator. Careful orientation of windows can be freed from direct sunlight.

From the foregoing, building forms that minimise the areas of roofs and east and west walls are advantageous in limiting solar gains. Multi-storey non-domestic buildings, except their top floors, have the considerable advantage of receiving no direct solar heating from above. Similarly, if single-storey buildings are elongated along the east-west axis so that the proportion of east/west walls to north/south walls is reduced, then good solar advantages will be experienced. Roof overhangs are more effective on north/south walls than east/west walls. Roof overhangs once heated are free to lose their heat to the ambient environment.

Table 2. Typical house design considerations in the three regions of Kenya

	Mombasa	**Nairobi**	**Eldoret**
Altitude	Mombasa is at 50m (164 feet) above sea level.	Nairobi is at 1790m (5900 feet) above sea level. Some areas are hilly areas open to strong prevailing winds.	Eldoret is at 2500m (8400 feet) above sea level.
Dry-bulb temperature	Annual mean max.: 29.0 - 30.5^{o}C Annual mean min.: 22.5 - 24.5^{o}C Diurnal range: 5.0 - 8.0^{o}C	Annual mean max.: 23.0 - 26.0^{o}C Annual mean min.: 8.0 - 14.0^{o}C Diurnal range: 10.5 - 17.5^{o}C	Annual mean max.: 18.0 - 25.0^{o}C Annual mean min.: 8.0 - 13.0^{o}C Diurnal range: 10.0 - 14.0^{o}C
Rainfall (mainly from April to June)	Annual mean 750 - 1500mm	Annual mean 700 - 1500mm	Annual mean 950 - 1250mm Max. at approx. 2500m
Humidity (3PM)	65 - 75%	46 - 53%	47 - 56%
Thermal comfort	Discomfort occurs mainly due to high humidity and high temperature. Air movement is necessary to reduce the effect of high humidity.	Climate mostly within thermal comfort ranges. Air change is more important than air movement.	Climate mostly within thermal comfort ranges. Air change is more important than air movement
Floor layout	House forms and plans provide cross-ventilation with the main orientation being along north/south axis.	House forms and plans tend to be compact. Orientation mainly faces north/south. Deep overhangs help to provide shaded and semi-enclosed outdoor space and/or courtyards.	Forms and plans very compact. Orientation is general. Cross-ventilation not required. Deep overhangs help to provide shaded area for livestock. Fireplaces are very common.
Windows & doors	Generally have large shaded openings, facing north and south for natural ventilation and natural daylight. Mechanical systems and artificial light sources are not seen as sustainable.	Windows comprising about 1/3 of north and south walls need to be operable. Mechanical systems and artificial light sources are not seen as sustainable.	Windows comprising about 1/3 of north and south walls need to be operable. Mechanical systems and artificial light sources are not seen as sustainable.
Building Materials	Low thermal mass walls and roofs with night-time cooling are recommendable	High thermal mass walls with night-time cooling not being recommendable	High thermal mass walls with night-time cooling not being recommendable

The energy consumption, monthly heating and cooling energy are shown in Figures 5-7.

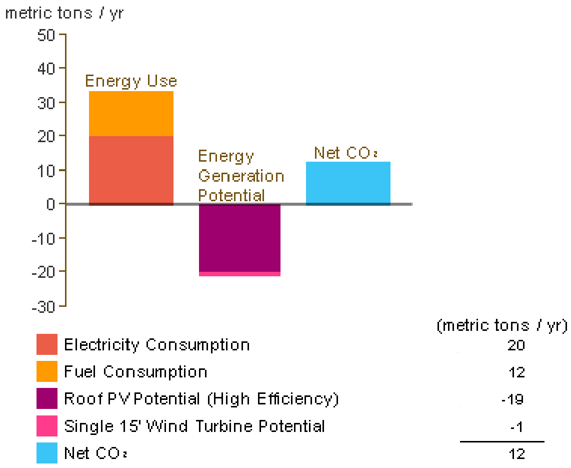

Figure 5. Simulated energy consumption in Nairobi house

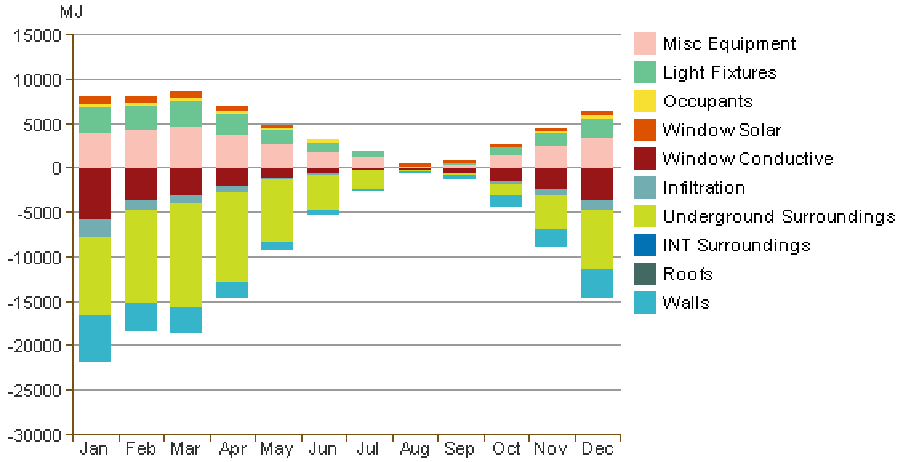

Figure 6. Simulated monthly heating energy in Nairobi house

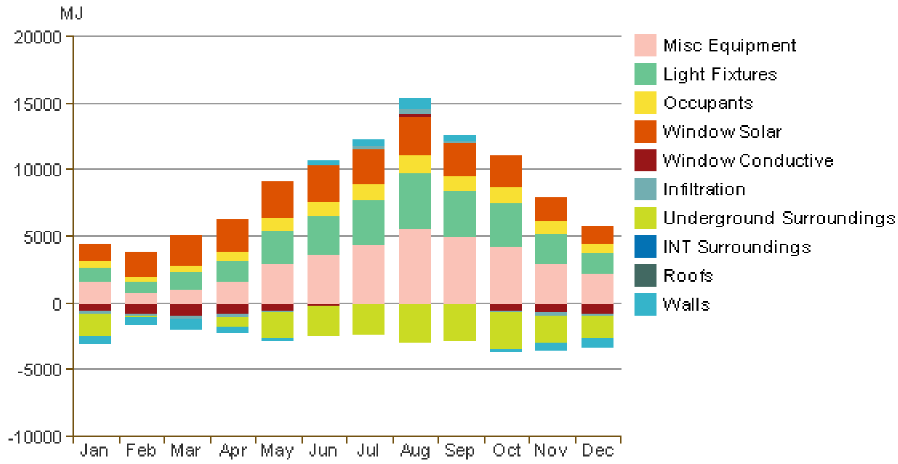

Figure 7. Simulated monthly cooling energy in Nairobi house

Observations from other studies

Balcomb said that dense building materials with the right mix of thermal conductivity and heat capacity, such as brick, concrete and concrete block, store and release considerable amounts of energy when they rise and fall in temperature. … Thermal mass is particularly effective in regions where the outdoor air temperature fluctuates daily above and below the building balance point (the exterior temperature at which a building is in equilibrium with heat gains equalling heat losses) (Balcomb, 1997:105-110).

Ogoli (2002) observed in Nairobi that Thermal mass affects the indoor temperatures in buildings. Na dpoposed a formula to predict indoor maximum temperatures for closed high mass buildings at equatorial high altitudes as follows:

$$T_{max}\text{-in} = T_{max\text{-}out} - 0.488(T_{max\text{-}out} - T_{min\text{-}out}) + 2.44$$

Where $T_{max\text{-}in}$ is the indoor maximum temperature; $T_{max\text{-}out}$ the outdoor maximum temperature; and $T_{min\text{-}out}$ is the outdoor minimum temperature.

Materials with high thermal mass have long time lag and moderating effects to temperature swings. An analysis of the mean radiant temperatures (MRT) measured in low mass buildings was plotted with exterior air temperature with the regression best fit is as follows:

$$MRT = 0.8372(\text{exterior air temperature}) + 5.3648$$

Indoor conditions are predicable.

Conclusions and lessons learnt

Dense building materials with the right mix of thermal conductivity and heat capacity, such as brick, concrete and concrete block, store and release considerable amounts of energy when they rise and fall in temperature. Thermal mass is particularly effective in regions where the outdoor air temperature fluctuates daily above and below the building balance point (the exterior temperature at which a building is in equilibrium with heat gains equalling heat losses).

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Design of an egg production shed under bioclimatic principles, case study Montería, Córdoba

Elizabeth Parra-Correa[1], Catalina Morales-Maya[2] and Alexander González-Castaño[3]

[1] PVG Arquitectos S.A.S. Medellin, Colombia. Email: elizabethparra@pvgarquitectos.com;
[2] PVG Arquitectos S.A.S. Medellin, Colombia. Email: catyca2@gmail.com;
[3] PVG Arquitectos S.A.S. Medellin, Colombia. Email: alexandergonzalez@pvgarquitectos.com.

Abstract: The poultry sector has high thermal requirements for an efficient development of the egg production process, which in a region of warm climate like the Colombian Caribbean, results in a high energy dependence in order to power air conditioning systems. The power outage periods, which are common in the region, interrupt the operation of these systems, resulting in a considerable risk of laying hens mortality, negatively affecting one of the products projected to be part of the national food security plan. This situation highlights the need to find alternatives that reduce energy dependence and increase the efficiency of this process. The purpose of the present investigation is to design an egg production shed under bioclimatic principles, that responds to the thermal requirements of the process, making use of passive strategies that diminish the environmental and economic impacts in this productive sector. Using solar analysis tools and analytical ventilation calculations, a design that responded to the environmental requirements of this productive process was developed. Once the shed was built, its environmental performance was evaluated, using on-site temperature measurements. The application of passive strategies resulted in energy savings of approximately 30% during the building operation, when compare to the traditional design, and in large periods of energy independence, as well.

Keywords: Bioclimatic design, energy efficiency, egg production.

Introduction

Colombia is highly vulnerable to climate change in many aspects, situation that has become more evident in the past 5 years. In the energy sector, for example, hydroelectric plants generate about 70% of the country's energy, which makes it greatly dependent on its water sources for its energy production. A decrease in the water level in its surface water sources and in precipitation, considerably reduces its capacity of generation energy, increasing the risk of using strategies such as rationing or the need to generate energy using fossil fuels, with high environmental and economic impacts, which have already been experienced in the past during lengthy periods of drought, caused by climatic phenomena such as "El Niño"(Blanco 2013).

The Caribbean region, located north-west of the country, is particularly vulnerable to this situation. It presents some of the most arid climatic characteristics of the national territory, in addition to a growing financial crisis of the public services company of the area which has compromise its ability to guarantee a proper, stable energy supply (Superintendencia de Servicios Públicos Domiciliarios 2016a; Superintendencia de Servicios Públicos Domiciliarios 2016b; Superintendencia de Servicios Públicos Domiciliarios 2017).

Numerous industries, whose production plants are located in this region, present a high dependence of electrical energy due to the specific requirements that each of the production process demand. The energy dependence of the poultry sector and egg production, for example, originates from the need to maintain strict hygrothermal conditions, necessary for the birds to maintain their level of productivity and to avoid the death of individuals.

At low temperatures, the food demand of the birds increases in order for them to maintain their energy level, and it decreases proportionally with the rise of the space temperature, in a range between 15.5ºC and 26.6ºC. This condition is maintained until an air temperature of 28.3ºC, therefore, the goal for poultry farmers is to keep this condition between 27.7ºC and 28.3ºC, in order to achieve the best production, with the smallest feeding amount, without compromising the integrity of the production birds. That is why, the Colombian Caribbean becomes a strategic location for this type of industries.

Like humans, birds are homeostatic organisms. When heat production is greater than the bird can dissipate through the usual processes of elimination (conduction, convection and radiation), their body uses a mechanism of latent heat loss, panting, which starts when the outside temperature exceeds 29.4°C. When the bird can no longer thermo-regulate itself, and its body reaches a temperature around 47ºC, called "mortal elevated temperature", it dies of "Caloric Prostration".

Similar to what happens to the human body and sweating, with the presence of a high percentage of humidity in the air, this condition inhibits the bird's ability to give it to the environment, and therefore to eliminate excess heat by means of panting. Thus, when the sum of the value of temperature and relative humidity exceeds 105, the birds will be in Caloric Stress (AgroParlamento n.d.).

The climatic conditions of the site, the poor material definition of the shed and the considerable internal gains generated by a concentration of more than 41,000 individuals, result in the need to use mechanical conditioning systems to maintain a thermal environment acceptable to birds, that for its operation requires a great amount of electrical power. In the event of a power outage, with the cessation of operation of mechanical environmental control systems, poultry farmers risk losing entire lots of productive birds, compromising the sustainability of the industry and at a large-scale, food security of the regions they provide for.

The purpose of the present investigation was to design a shed under bioclimatic principles, which responds to the thermal requirements of the industry, using passive strategies that reduce the environmental and economic impact of this productive sector, and that decreases its energy dependence, in order to maintain the welfare of productive birds.

Characterization of the site location

The weather condition of the municipality of Montería, where the project is located, is classified as a very dry-warm climate. The average outdoor temperature is 27.8ºC, reaching values between 32 and 34ºC throughout the day. At dawn, the period in which the lowest temperatures are recorded, this varies between 22 and 23ºC. The relative humidity of the air, on the other hand, oscillates during the year between 76 and 82%, being greater in the months of October and November (IDEAM 2014).

Considering the strict hygrothemic requirements necessary for the birds to be productive without presenting signs of stress, the climatic characteristics of the site, constitute a major challenge for a design under bioclimatic parameters.

Poultry production shed design background

The challenge of designing efficient sheds has resulted in multiple architectural typologies, according to the breeding parameters established by each production farm. In the present investigation the design team worked closely with the company Santa Rio Shed, AVES EMAUS LTDA, and the parameters adopted by this company. This farm already had a traditional shed in the same site where the object of the present study was built.

Both sheds have the same dimensions in their floor plan (104.86 m long and 15 m wide) with the longest façades oriented toward north and south, and with an equal bird occupation (41,000 birds), criteria that allowed the team to make a quantitative comparison with the new shed after the last was built.

The traditional shed operates under the "controlled environment" model and requires for its operation 18 air master fans, of 1.5 HP, 3f, 60hz v130-3, and two water panels located in the central part of the long facades, turned on 100% of the time. This means a permanent, 24 hours a day, energy consumption, for the operation of the turbines, as well as a high water resource requirement for the operation of the panels.

The temperatures resulting from this air conditioning system, range between 24.3°C and 33.1°C, while relative humidity remains between 62.5% and 97.5%.

Taking as reference the amount of Kwh registered in the utility bills of the 6 months prior to the start of the consultancy, it was determined that the monthly consumption of the traditional shed is, on average, 20,020 kwh. Each kilowatt costs COP$ 440 (0.15 USD), which equals a total monthly payment of COP$ 8,808,800 (USD$ 2,995).

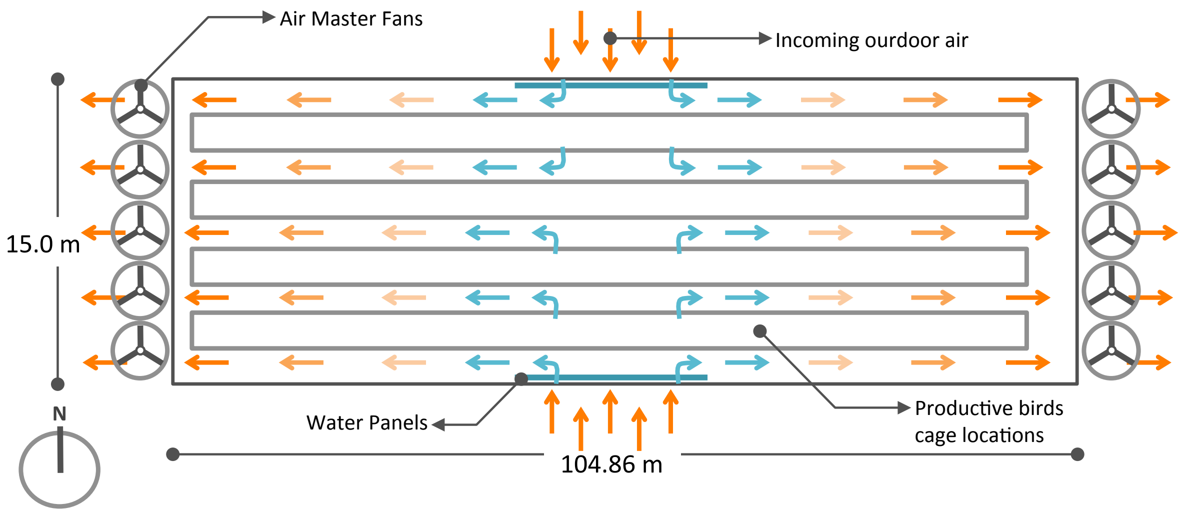

Figure 1. Scheme of distribution of the existing shed.

Methodology

As a starting point for the design of the shed, the basic spatial and environmental requirements necessary for an egg production process were considered as design guidelines, which were defined based on the standards adopted by the contracting company.

Spatial Requirements

The space was composed of a metal structure of rectangular plant, raised on concrete columns up to 3 meters off the ground; with a gable metal roof, with a slope of 19º, which had to respect, for the entire inner area, a minimum clearance height of 3.5m. The floor, for operational reasons, was defined as a metallic mesh. The four façades of the space are open, protected from direct solar radiation by a woven mesh composed of fibres of high resistance polyethylene.

Thermal requirements

Considering that the productive birds should not receive direct solar radiation at any time, the dates and times in which each façade presents the most unfavourable condition of solar incursion, that is to say, the periods of time during the day and the year, in which each orientation receives the solar beam with the greatest inclination, were determine, making use of the solar shade diagram designed for the latitude 8.62ºN, corresponding to the city of Montería (Melguizo Bermudez & Uribe Toro 1987), in order to define the extent and the slope of attachment of the lateral sun protection elements.

On the other hand, the constant circulation of the air volume of the space is an effective tool to help maintain the indoor temperature and control the humidity of the environment, especially in this case, where the birds also contribute with a considerable additional heat and moisture load, to the already high values of both variables in the pre-existing climatic conditions. Each bird requires approximately 14.4 m3/h of air, and considering that the shed should house about 41,000 individuals, it was estimated that the air volume should be renewed 62 times per hour.

Considering the irregularity of the natural air currents and the calm period, which for this region is almost 40% of the time, it was decided to design a natural ventilation system based on the air convection physical principle, taking as inlets the mesh of the floor and the open façades, and locating the outlet in a central opening on the main roof, protected from the sun and rain by a secondary cover. To estimate the size of area of openings, the ASHRAE method for “when the airflow is mainly due to the temperature difference” was used (see equation E1) ((ASHRAE, 2001 as citated by Yarke, 2005).

$$A = \frac{Q}{116\sqrt{h(T_i-T_o)}} \qquad \text{E1}$$

Where A is the opening area (m^2), Q is the design air flow rate (l/s), h is the height between the inlet window and the outlet window (m) and Ti and To are the average indoor and outdoor temperatures, respectively.

Results

The space resulting from the spatial and environmental premises is shown in Figure 2.

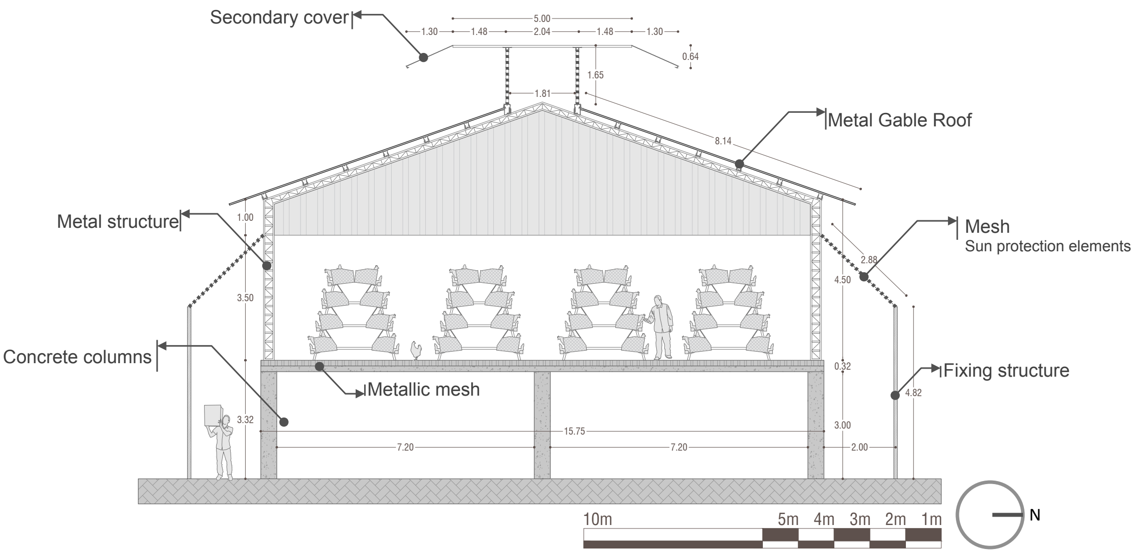

Figure 2. Schematic section of the new shed.

As it was stated that laying birds should not receive direct solar radiation, it was defined that the protection elements should guarantee full control of this condition during an hourly range between 7:00 am and 5:00 p.m., in both, open façades and roof. Using the shade diagram of the city of Montería, it was identified that for the limits of the hourly range of protection, June 21st and December 21 st presented the most inclined solar incursion in the north and south façades, respectively, and based on this information, the dimensions and inclination of fixing of the sun protection elements was determine as shown in Figure 3.

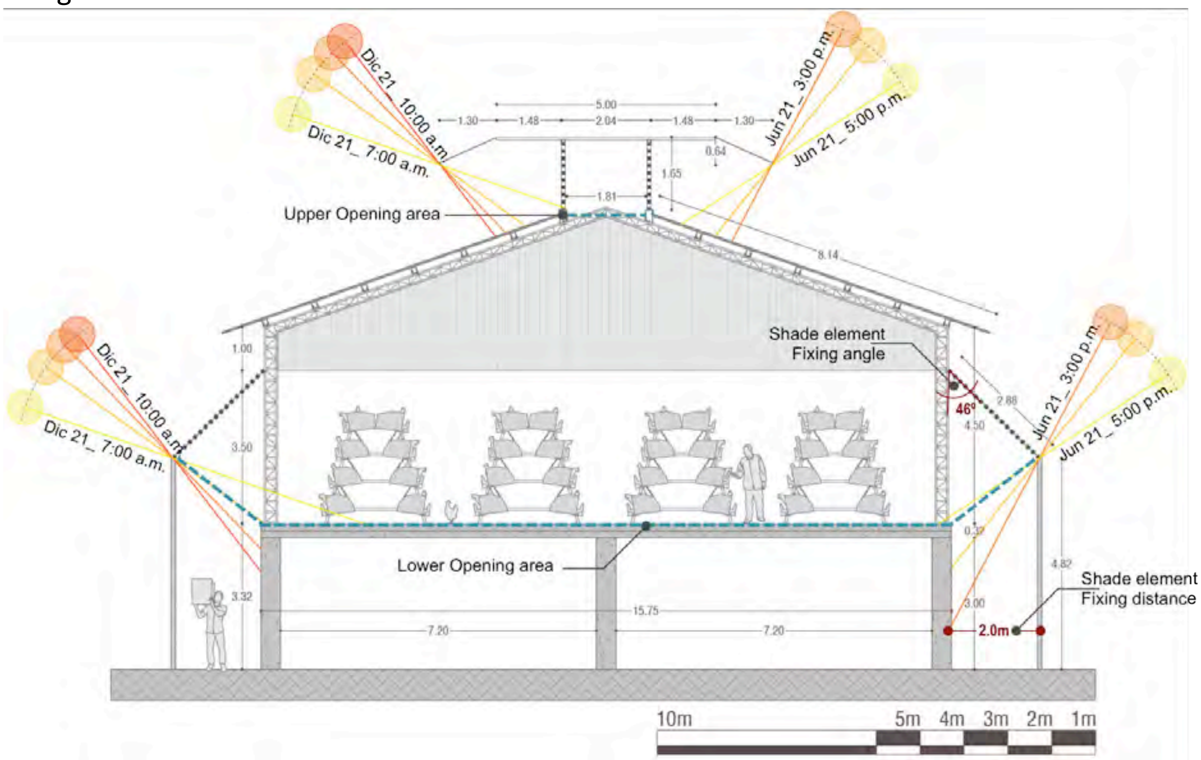

Figure 3. Solar incursion verification and openings location

In order to reach the 62 air changes per hour necessary to obtain an adequate ventilation of the shed, the openings were dimensioned considering a thermal delta of 1.5ºC and a difference of heights, between openings, of 8.25 m.

Since the availability of surfaces for the location of openings was considerably smaller for the upper vent, an adjustment was made to the area according to the "increase in flow due to a difference of size between the openings" figure presented by the ASHRAE method (ASHRAE, 2001 as citated by Yarke, 2005). As a result, the equation determined that the space required a lower opening area of 1005.29 m2 and an upper opening area equal to 168.59 m2, located as shown by Figure 3.

Information Comparison and analysis

Once the shed was built and put into operation, the internal temperature and relative humidity were monitored every half hour for two weeks in order to evaluate its environmental performance. A total of 648 measurements were obtained for each variable. During this period the outside temperature values moved in a range from 25°C to 30°C, with the relative humidity ranging between 76 and 82%; usual weather conditions for that time of the year.

According to the data, 51% of the time, the indoor temperature was below the desired upper limit (28.3°C). On the other hand, when adding the values of both variables, temperature and relative humidity, to determine the thermal stress indicator, it was obtained that 67% of the time evaluated, this indicator exceeded the reference value (105). What makes this last value, the most accurate tool to determine the energy autonomy of the new shed.

Based on the evaluated period of time and the totality of the recorded data, it can be concluded that 33% of the time the shed can operate autonomously, without mechanical assistance; 18% of the time, it would require such assistance to reduce the humidity of the environment by dehumidifying or by increasing air circulation, and 49% of the time, it will require it to achieve the desired air temperature values.

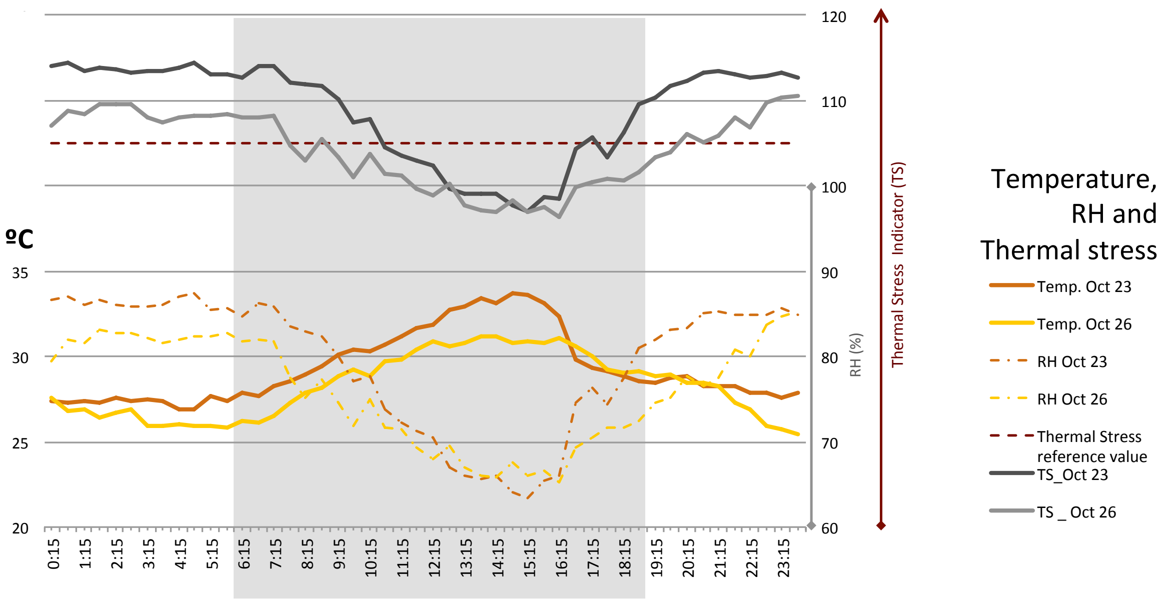

Figure 4. Temperature, Relative Humidity and Thermal Stress Indicator (TS) for the 23rd and 26th of October, 2016

Figure 4, shows the values of indoor temperature, relative humidity and thermal stress indicator, obtained for two of the evaluated days, October 23 and 26, in which respectively, the highest and lowest temperature values were recorded, thus containing the total range of temperatures documented inside the space.

On the day with the highest recorded temperatures, the shed presents conditions that allow it to operate autonomously 29% of the time, while during the day with the lowest recorded temperatures, it reached an autonomy of 50%, presenting a difference between the two cases, of approximately 5 hours.

It could be speculated that periods of thermal stress would occur more frequently during the day due to the increase in the outside temperature, which in the afternoon usually exceeds the desired range of values. However, as the figure illustrates, the values of the thermal stress indicator that exceed the reference value are recorded mostly during the night and dawn. During the day, solar radiation favours the exchange of heat with the outside, increasing the capacity of the natural ventilation system, which is based on the convection principle, to renew the volume of the air.

During the night, on the other hand, although the temperature drops considerably, the ventilation system loses efficiency and the space stores more humidity, inhibiting the mechanism of latent heat loss of the birds, and therefore requiring the support of the mechanical ventilation system.

Conclusions

The application of bioclimatic principles and passive solar design to the design of the new shed allowed obtaining energy autonomy of approximately 30% of its operating time. Considering that according to climate statistics (IDEAM 2014), the most adverse conditions in terms of humidity are in October and November, this percentage is expected to increase.

The consumption records registered in the last 6 months, show that, on average, the shed designed under passive design criteria consumes 14,813 kwh monthly, that is 5,207 kwh month less than the traditional shed; this is equivalent to an economical saving Of COP$ 2,290,933 (USD$ 800).

Although the initial concern expressed by the contracting company was the high internal temperatures, the design actions taken managed to maintain that condition within the desired limits 51% of the time. However, the measurements showed that the presence of high humidity in the environment, recorded during the night and dawn hours, is the climatic factor that limited the most the possibility of operating without mechanical assistance throughout the day.

Despite this condition, according to the production company, when the mechanical ventilation support system ceases to function due to irregularity in the public energy service, the mortality of birds during periods when there is high humidity in the environment, and even at times when the temperature of the interior air of the new shed is higher than 28.4°C, is considerably smaller than that presented in the traditional sheds when for this same reason, its air conditioning system is suspended; going from a risk of losing almost 100% of a batch of productive birds, to less than 5%.

Based on what was concluded with the analysis of the data presented here, it is proposed, as an additional measurement, to lift the sun protection mesh during the night time, between 19:00 and 7:00 h, in order to potentiate cross ventilation throughout the period of solar radiation absence. The impact of this measure will be verified in subsequent environmental monitoring. An additional measure could be to reduce the number of birds present in the shed, in order to lower the heat and humidity loads in the environment. However, this would mean that the company would require a larger infrastructure to house the same amount of birds, which could prove to be economically unfeasible.

Acknowledgments

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Design to Thrive

Brazilian Modernist Envelopment Elements Reinterpreted through Precision: a Case Study on Energy Efficiency and Environmental Comfort in an Experimental Building

Aderson Passos[1], Karoline Cordeiro[1], Nayana Castro[1], Bruno Raviolo[1], Natasha Catunda[1] and Daniel Cardoso[1]

[1] Departamento de Arquitetura e Urbanismo da UFC, Universidade Federal do Ceará - UFC, Fortaleza, Ceará, Brazil, Av. da Universidade, 2890 - sala 11 - Benfica

Abstract: In some latin-based languages, the word *precision* means both accuracy and necessity. Through history, architects have thrived creating solutions both fit for their contemporary methods of fabrication and with a certain level of performance towards our needs, such as environmental comfort. Perforated elements in facades and roofings in brazilian modernist buildings are examples. Although, while necessity has usually been addressed, accuracy is commonly neglected when further customization is needed for optimal improvement in thermal and lighting comfort, both often needing accurate analyses of nature's behavior. This is usually due to the unavailability of fabrication logistics proper for mass customizing buildings elements. This paper studies how these architectural elements can evolve, starting from old inaccurate designs, then presenting a case study of an experimental building in Brazil built for a research on energy efficiency according to specific bioclimatic necessities that adapted, combined and optimized the original concepts of these elements using computational simulations, parametric modeling and genetic algorithms. Local technological conditions were respected, dealing with the low amount of customization allowed by accessible solutions and still delivering a reinterpretation of modernist architecture that, for the accurate adaptation of the envelopment to local climate, local language can understand by true, latin-based *precision*.

Keywords: Modernist Architecture, Environment, Parametricism, Computational Simulation, Solar Control.

Introduction

The construction of buildings is an activity ten thousand years old. Only about 130 years ago these buildings started using electricity, and 115 years ago they began with the possibility of using air conditioning systems in their interiors. Thus, it can be concluded that in most of their history, buildings had to be adapted to the climate in order to provide adequate environmental comfort conditions for their users (Romero, 2012).

Architecture underwent significant changes in the years following the incorporation of artificial conditioning systems. The so-called International Style, in turn, as a consequence of its indiscriminate use, brought the creation of an architecture alien to its climatic context, one in which what was to be specific for a given reality became a general rule. As a result, the aspects of environmental comfort were left out of this style's design premises (Lamberts et al, 2014). Thus, inadequate architecture generated a demand for active systems to guarantee environmental comfort, consequently increasing energy costs.

Soon after, the modernist movement in Brazil comes to confront this strand by creating its own architectural features, mainly taking into account its cultural and regional aspects. Brazil's great contribution to modernist architecture was the implementation of creative solutions to prevent the entry of heat and direct light through glass surfaces with the aid of articulated sunshades. These innovations were previously recommended by Le Corbusier, however it was in Brazil that they found a favorable scenario to be incorporated into modernist architecture and adapt this language to a tropical reality (Goodwin, 2012).

The use of these elements in brazilian architecture brought advantages for the buildings that incorporated such solutions and, nowadays, their optimization during the design process can be facilitated by the use of computational simulations. The adoption of these simulations as evaluation tools for a building’s performance is very important for the reduction of energy demand if carried out in early stages of design (Gonçalves et al, 2015).

The materialization of performance-oriented projects often involves concepts such as complex geometries and mass customization. For both industrial production and assembly on a construction site, Computer Aided Manufacturing (CAM) technologies, such as CNC or robotized machines, may be required (Dunn, 2012). The conflict lies in the high costs involved, as these technologies are often confined to rapid prototyping even in high technology environments. Thus, it is necessary an approximation between the design and the techniques to be used in its execution, seeking suitable middle grounds, feasible for the capacity of local industries but that do not compromise the performance of the project, reducing the costs of production and installation to facilitate the process of implementation.

Considering the presented context, this work aims to present a case study where computer simulation and parameterization tools were used to optimize the dimensions and spacing of solar protection elements commonly used in brazilian modernist architecture in order to maximize indirect natural illumination inside a building which will function as the administrative headquarters of a company, in order to achieve energy efficiency. This Experimental Building is located in a brazilian coastal city in the state of Ceará, characterized by a hot and humid climate, with intense solar radiation throughout the year. In addition, it also has the objective to combine the solutions found in this process with the local technology, in order to make them feasible, since the building would, in fact, be built.

Historical Evolution of Solar Protection Elements

Permissive elements of solar protection for natural lighting and ventilation were already being applied to buildings in different places and times in architectural history (Bittencourt, 1995). Zenithal openings in renaissance domes, brises-soleil at early european modernist production and arabic muxarabis[1], inspiring the brazilian cobogós[2] as cultural heritage of the country, were examples of the different versions of these elements, as found outside Brazil.

On the international scene, Frank Lloyd Wright made use of prefabricated blocks of concrete, called “textile blocks”[3], which relate to the cobogó but present a more solely aesthetic aspect, emphasizing the monumental and plastic character of buildings (Figure 1).

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[1] Light framework constructed with wooden lines, used to partially close internal environments.

[2] Brazilian perforated blocks, usually made of cement or ceramic, used to complete walls allowing greater ventilation and luminosity in interiors. The name is an acronym from the names of Coimbra, Boeckmann and Góis, the architects and engineers who invented it in the beginning of the 20th century (Sunguroglu, 2008).

[3] Construction system perfected by Wright in the Californian period (1914-25). It is a construction system based on the use of concrete blocks, decorated and prefabricated with the aid of wooden mats used as formwork in the concrete walls molded in loco (Folha de S. Paulo, 2001).

Another example is the Institute of Zoology of Nancy in France (1932-1933), which brings a reinterpretation of Wright's blocks (Figure 1). The cement blocks applied in this building additionally confer an unquestionable aesthetic effect, evidencing the constructive demand, because the designs made in the blocks made them lighter, facilitating handling and transportation (Bauer et al, 2011).

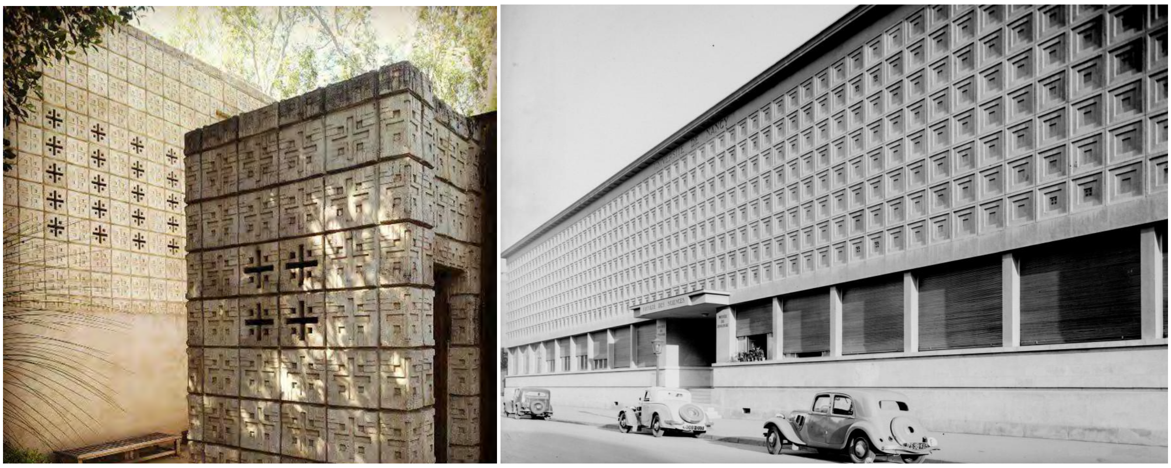

Figure 1. Frank Lloyd Wright, La Miniatura/Millard House, 1923 (left). Zoology Institute of Nancy (right).

Contemporary to the Zoology Institute of Nancy (France) and already within the brazilian national context is the modernist building of Olinda's Water Tower, from 1936, where the cobogó was used in large scale for the first time in Brazil. The use of the cobogó in this building, besides having the functional characteristic of providing constant aeration and structural lightness, presents a symbolic sense of dialogue between tradition and modernity, thus constituting a symbol of modernism (Marques et al, 2011).

The brises-soleil were also elements used in some modernist works. However, due to its high cost, the use of cobogós was more prevalent in brazilian architecture. Besides these, other solutions for solar protection elements permissive to natural lighting and ventilation were employed in modern Brazilian architecture, such as, for example, concrete flaps surrounding external frames, ventilated parapets, among others.

In Brazil, the design of these elements is still restricted to conventional shapes due mainly to production costs. During design, these elements are often given dimensions through the use of conventional techniques, using solar charts and simple geometric calculations, or even by solely aesthetic criteria. There is, therefore, space for improvements in the performance of these elements with the use of digital tools.

Modified Elements

The following are the modifications of the previously presented elements, developed in this work from adaptations through computational analyses of solar incidence in the facades and roofing of the Experimental Building in question.

The building has an elliptical shape, the result of form finding simulations, whose objective was to maximize natural ventilation and illumination captation, in order to guarantee the users' environmental comfort through passive strategies and thus reduce the energy consumption of the building.

Brises-soleil were used in the southeast facade, since it receives more ventilation and due to the fact these elements do not disturb the wind passage. Cobogós were used in the northwest facade, which needs better solar protection since it receives more thermal load.

Conceptual Modifications

Cobogós

Based on more conventional and structurally viable designs, square modules made of concrete blocks with a 20 cm inside to outside thickness were proposed with minimum structural inner thicknesses of about 3 cm for the greater use of natural ventilation and the smallest frontal dimensions possible for the elements to still block direct radiation incident on the entire curvilinear facade of the building.

Due to the fact that the solar incidence occurs differently along the curvilinear facade, three different sizes of cobogós were dimensioned, basically one for each orientation: north, northwest and west (Figure 2). The dimensioning of the pieces was defined by simulations with software Weather Tool, whose objective was to prevent direct solar radiation from entering the building until the closing time of activities, at 4:00 p.m. (Figure 3). According to Figure 2, the square openings have, respectively, from left to right, sides of 6, 8 and 16 cm, ranging from westmost to northmost blocks of cobogós.

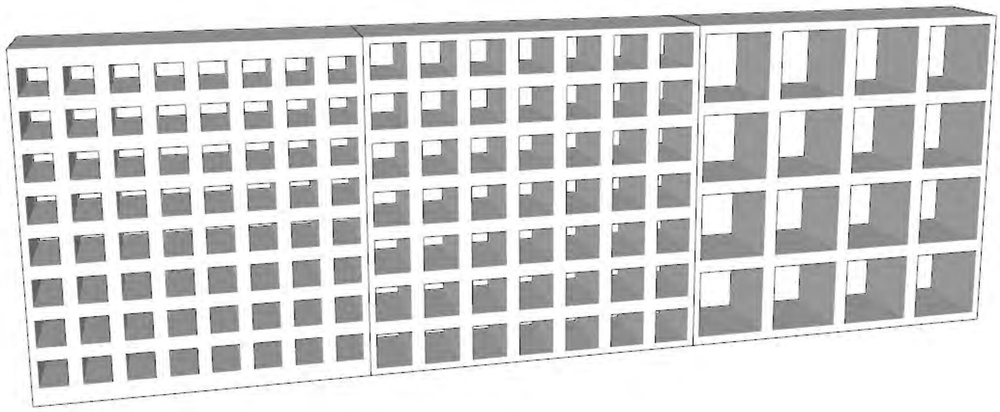

Figure 2. Variations of cobogós optimized for one of the curvilinear facades of the building (author).

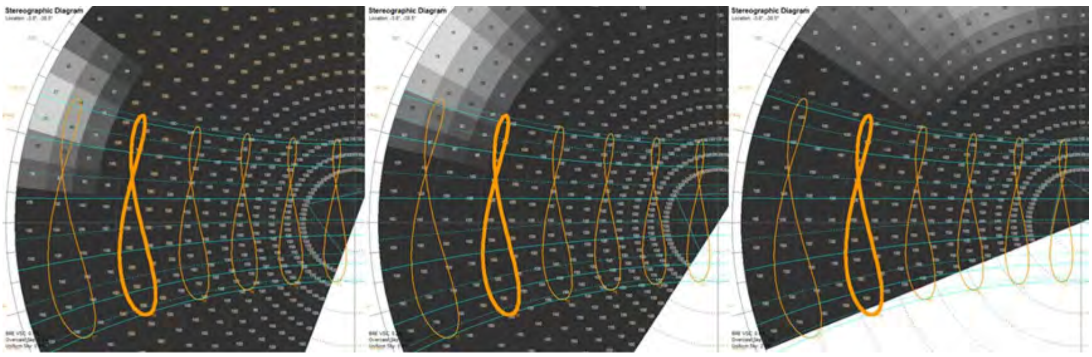

Figure 3. Solar charts for the three simulated orientations, showing dark spots of 100% shading for all solar positions until the analemma of 4:00 p.m., highlighted in bold orange (author).

Brises-soleil

In order to allow the passage of wind, protecting the interior of the building from direct solar radiation and taking advantage of external natural light, brises-soleil were used in an analogous way to the cobogós, on the opposite facade of the building, varying its geometrical properties along a curvilinear path of varying solar incidence (Figure 4).

Figure 4. Possible parametric variations of the brises-soleil adapting to the solar incidence along the curvilinear facade of the Experimental Building (author).

The Rhinoceros 3D modeling tool, along with the Grasshopper parametric plug-in, was used in conjunction with the Geco and Ecotect solar simulation components to adapt the geometric parameters of the brises-soleil, where their gradual increase of inclination, depth or quantity follows the orientation of the facade from south to east.

The variation of the brises-soleil's inclination generates continuous pieces with the entire interval between the points of largest incidence angle of the sun and the points where the sun hits the facade more perpendicularly being protected by a sequence of cross sections of the brise-soleil with inclination angles progressively larger and interpolated throughout the piece. For its execution, no easy access and implementation solution was found in terms of materials and techniques that enabled this design. Similarly, the depth parameter of the brises-soleil could be varied throughout the piece, which would be possible to execute, but not convenient given it would use a lot of horizontal space. In addition, due to the size of the facade of more than 80 meters in length, this solution would need to be made with several smaller pieces. The option of varying the amount and spacing of brises-soleil along the facade, as in the last image of Figure 4, has thus become the most feasible. It was implemented through the use of light and reflective aluminium composite panels, doubled, structured in metallic frames and stacked in the horizontal position. Each horizontal piece of the brises-soleil had approximately 3 cm of height and 40 cm of depth, and were stacked with different vertical distances from each other of 44, 36, 30, 28, 26 and 25 cm, respectively, from southmost to eastmost sections of the southeast facade.

Skylight and light shelves

Combining the concepts of light shelf and skylights, a system hereby called reflective shields was used for the solar protection of the zenithal openings applied on the roof. These openings were made from the removal of the tops from the ribbed slab, which functions as a second level of roofing for the indoor air conditioned ambients. These shields were positioned beneath the zenithal openings and were specified with a reflective material on their upper surfaces to reflect the zenithal light directly incident on it, thus allowing the diffuse entry of natural light into the building (Figure 5).

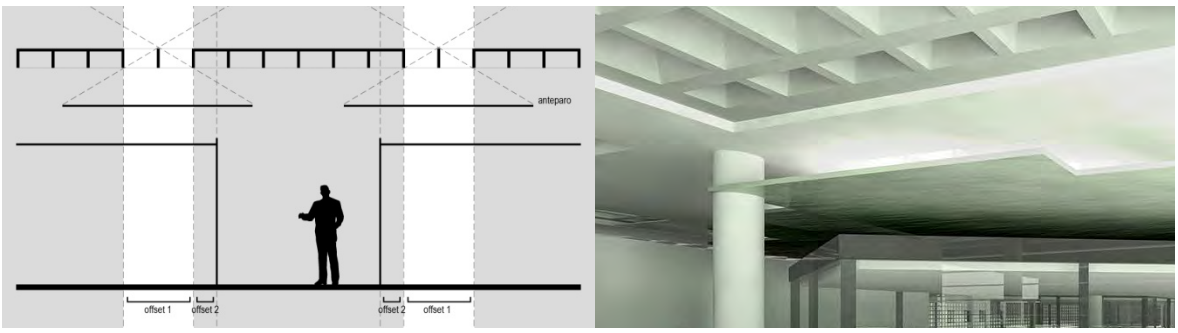

Figure 5. Schematic section of the reflective shields (left) and digital perspective (right) (author).

Further arrangements were made for the manner in which the openings were chosen on the slab and how to protect them with the reflective shields. Parametric modeling was used to link the calculation of the dimensions of the shields to the slab thickness and the possible angles of incidence of the sun. For this, the spacing between reflective shields and slab was optimized through genetic algorithms, in order to allow the reflection of a greater amount of light to the interior of the building. Adaptations were made throughout the work so that the execution of the shields was compatible with the modulation of sheets of reflective materials available in the local market. The final proposed design made use of doubled aluminium composite panels, with an inner layer of heat absorbing foams.

Optimizations and Results

Simulations

Simulations with the Diva software were made to investigate the contribution of the cobogós to the internal illumination of the building, without any other openings in the envelope being modeled (Figure 6). This gives a graph of daylight factor, which indicates the percentage of illuminance incident relative to the external incidence of the building, i.e. how much of the external illuminance is admitted into the building (Mardaljevic, 2009). In the result, a greater diffuse illumination is observed in the northernmost segment of the curvilinear facade, due to the larger sizes of the cobogós. At no point in the facade was allowed the incidence of direct sunlight inside the building within its operating hours, from 7:00 a.m. to 4:00 p.m. Cobogós and all other elements in the scene were modeled in Diva with a reflectance value of 70%, corresponding to a generic rough painting in the white color, and all other attributes remaining at their default values.

Similar to the cobogós, simulations were made with the brises whose pieces increase in quantity as they approach the segment of the facade that receives solar incidences of more perpendicular angles. Likewise, in no point was the entrance of direct radiation admitted, with diffuse levels of light being observed in the south of the building in the case of brises-soleil (Figure 6) reaching maximum values much higher than with the cobogos, in up to 6% of daylight factor. Brises were modeled in Diva with a reflectance value of 80%, corresponding to a polished white metallic surface, and all other attributes remaining at their default values. Other elements in the scene were modeled with the same material properties as the cobogós in their simulations.

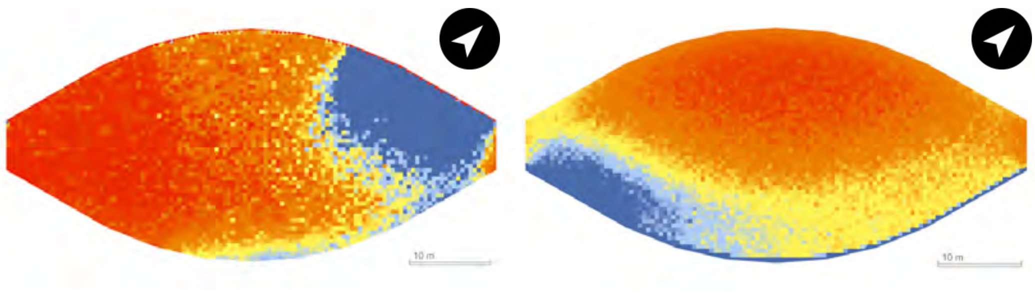

Figure 6. Daylight factor simulations. On the left, the isolated application of cobogós and their contribution to the natural lighting of the building, in a gradient of 0% to 0.5% of the external illuminance value (blue are the highest values). On the right, the isolated application of brises, in a gradient of 0% to 6% DLF (author).

Parametric Modeling and genetic algorithms

With reflective shields, computational optimization techniques were used, coupled with the versatility of parametric modeling to obtain maximum levels of illuminance within the building. Mathematical relationships were established between dimensions of the ribbed slab on the roof of the building and the reflective shields positioned just below (Figure 7). The relationships were implemented in the Grasshopper parametric modeler (Figure 7) so that whenever the shields were repositioned to a new distance from the slab, they were automatically resized in a way that at any given time of the day there is no possibility of direct sunlight entering through the roof's zenithal openings.

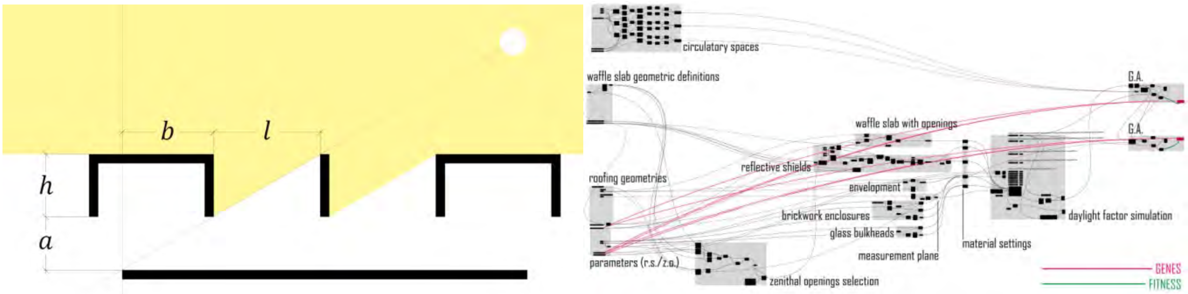

Figure 7. Reflective shields and optimized variables (left) and the algorithmic definition for the optimization of reflective shields with the use of genetic algorithms (right) (author).

By maintaining relations between variables, the modeler then investigates new combinations of openings and spacings. The Galapagos component of Grasshopper is responsible for the implementation of genetic algorithms that, in a single procedure, both use results from Diva's daylight simulations to define the performances of each tested combination of openings and spacings, as well as guides the selection of new combinations to be tested, with the tendency for each new generation of found combinations to have even greater performance values. The algorithmic technique consists of an analogy to darwinian mechanisms of natural evolution, where the environment promotes a selection of pairs compatible with a greater chance of generating an offspring of greater fitness. This optimization in the search for better combinations of parameters avoids the need for an extensive combinatorial analysis of all possibilities (Besserud et al, 2008). Finally, the best combination of the last generations is selected to be implemented in the construction of the building (Figure 8). The simulations carried by the optimization procedure introduced the reflective shields as surfaces modeled with material properties of reflectance of 90%, corresponding to polished metal with a mirrored finish, in order to maximize lighting gains, and all other properties remaining at their default configurations. These simulations isolated the reflective shields as a light gathering solution, ignoring light coming from the facades, for faster calculations due to a lesser amount of geometries, with no cobogós or brises.

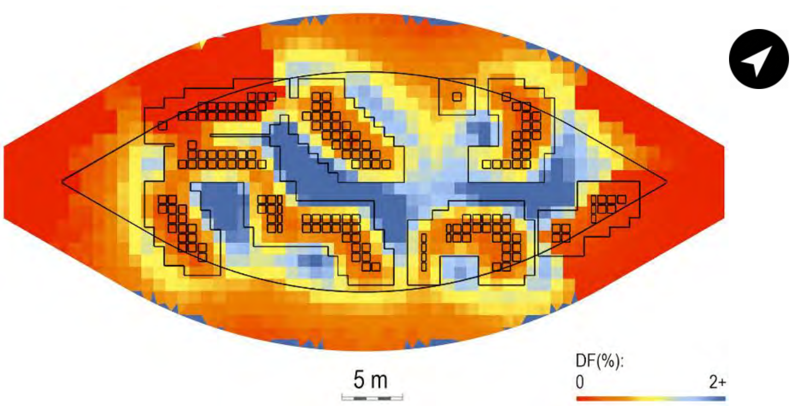

Figure 8. Final shapes of the reflective shields (pixelated outlines) and openings selected by the computational optimization procedures (squares) (author).

Conclusions

The process of optimization of solar protection elements through the use of daylight simulation and parameterization software made it possible to increase the use of indirect sunlight in the interior of the building, making clear the contribution of the customization of geometric parameters and their adaptation along the facades. The Experimental Building ended up assimilating the reinterpretations of modernist elements in a new language that, by implementing familiar materials and constructive techniques, nevertheless managed, in a subtle way, to stand out by the presence of variation and personalization of its geometrical characteristics, always according to functional aspects, in a precise - or *preciso* - way.

Figure 9. Indoor photography of the Experimental Building in its final stages of construction (authors).

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Performance Evaluation of New Generation Cement Based Insulating Material for Equatorial Tropics: Impact Study on Naturally Ventilated Buildings in Singapore

Priya Pawar[1], Yang En- Hua[2], Wan Man Pun[3]

[1] Energy Research Institute, Nanyang Technological University, 50 Nanyang Drive, Singapore 637553, priya.pawar@ntu.edu.sg
[2] School of Civil and Environmental Engineering College of Engineering, Nanyang Technological University, Singapore 639798, ehyang@ntu.edu.sg
[3] School of Mechanical & Aerospace Engineering College of Engineering Nanyang Technological University, Singapore 639798, mpwan@ntu.edu.sg

Abstract: Buildings in the equatorial tropics face a unique set of challenges to achieve energy efficiency and sustainability targets. The biggest consumer of electricity in these buildings are the ACMV systems. Solar heat gains through building envelopes contribute about 50% towards cooling loads in the tropics. Passive methods to reduce these solar gains from the envelope's surfaces could result in significant cooling energy savings. This paper focuses on the thermal performance evaluation of a new generation lightweight cement based material applied with a thickness of 5 cm on the walls and 20 cm on the roof. The experiment is carried out in a real- time on real building in Singapore. It was observed that the indoor ambient air temperature was reduced by up to 4.6°C and an annual heat gain reduction of up to 60% could be achieved for a residential building in the tropics.

Keywords: Tropics, Thermal Heat Flux, Passive Technology, Insulation, Sustainable Buildings

Introduction

It is well established that building sector is a major contributor towards global CO_2 emissions. In Singapore, the construction industry has been recognised as the third largest contributor of its overall emissions which was accounted for about 16% in 2005 (NEA, 2008). To provide a long-term sustainability solution to mitigate emissions from the building sector, Singapore's Building Construction Authority (BCA) launched its Green Mark Certification Scheme in 2005 under its first Green Building Master Plan. Since its launch, the scheme has seen a 16% decrease in the Energy Utilization Index (EUI) of office buildings in Singapore in 2013 (BCA, 2014). However, the most effective decrease in energy consumption is possible when the building's passive design strategies can efficiently decrease its cooling demands.

Buildings in the equatorial tropics face a unique set of climatic challenges. The climatic conditions here are classified as hot and humid throughout the year with high sun angles. Studies conducted in the tropical climate of Singapore to quantify the electricity consumption of Air Conditioning Mechanical Ventilation (ACMV) systems have concluded that 57% of the total energy consumption (Zingre et al, 2016). Another study quantifies that 30% of this cooling energy demand is due to the solar heat gain from the thermal heat flux through the opaque surfaces of the envelopes (roof and walls) of tropical buildings (Zingre et al, 2015). This evidently highlights the need of special attention while considering construction material as a passive strategy to curb the heat flux through the envelopes in hot and humid climate.

In the past, increased thermal resistance for envelopes by adding insulation material in tropical buildings was considered as an unsuitable passive strategy. However, with new studies on vertical greenery, green roofs and double skin facades have lent a different perspective to increased thermal resistance and its benefits for tropical buildings along with its application for various building typologies. This paper focuses on the study of new generation cement based insulation material on a naturally ventilated space to quantify its impact on various surface and indoor air temperatures of the test building as well extrapolate potential energy savings through computer simulations. Furthermore, impact of this study could allow building construction industry of hot and humid climates to revise its perspective on the use of external insulation on energy efficiency.

Methodology

The study was carried out in two stages. A "side by side" testing methodology was implemented to map the performance of the material. Details of the methodology are explained in section "experimental set-up". Data collected from the testing was used to calibrate a simulation model to validate the test results as well as to calculate the possible energy savings. The site selected was naturally ventilated with a mechanical fan to enhance thermal comfort by increased air velocity.

The Site

The test site was located on Nanyang Technological University Campus (NTU), Singapore. The experimental study was undertaken as part of the university's Eco-Campus initiative according to which the university is committed to reducing 35% of its energy, waste and water intensity by 2020 (baseline 2011) (NTU, 2012). For the investigation, a student's dormitory building – Hall of Residence 4 was carefully selected from other hall of residences (which are naturally ventilated) after evaluation of its orientation, massing, shading and ventilation.

Experimental Set-Up

Two identical blocks (26 and 27) at the hall of residence 4 on NTU campus were selected for comparative "side by side" study. Each block was a single storey building (10m x 4m) with a solid flat roof of 150 mm thick concrete and 12 mm plaster with a total of 40m^2 roof area as seen in figure 1. The blocks have a north-south orientation and have four identical dormitory rooms (2.5m x 4m) that are naturally ventilated with one window (0.8m x 1.6m) facing the south as seen in Fig 1 . Block 26 is considered as the "Original" cell and was not retrofitted with the insulation material. It was left as is to get benchmark case for a comparative study. Block 27 was retrofitted with 50 mm of insulation material on the walls and 200 mm on the roof (external application) and finished with the original paint colour. This was the "Test" cell used to gather data for performance evaluation from January to July 2016. Both cells were fitted with Resistance Temperature Detectors (RTD) on the inside and outside of each Test cell as seen in Figure 1 as well as indoor air and humidity sensors. Block 27 was also fitted with a pyrometer, pryheliometer and a solar tracker. Portable solar spectrum reflectometer and portable emissometer were used to measure solar reflectance and thermal emittance as seen in Figure 1. For the Test Cell, sensors were fitted on the roof, ceiling, east and south wall as north wall faced the corridor and there was no west wall available for evaluation for this cell due to the architectural design of the building as seen in Fig 2.

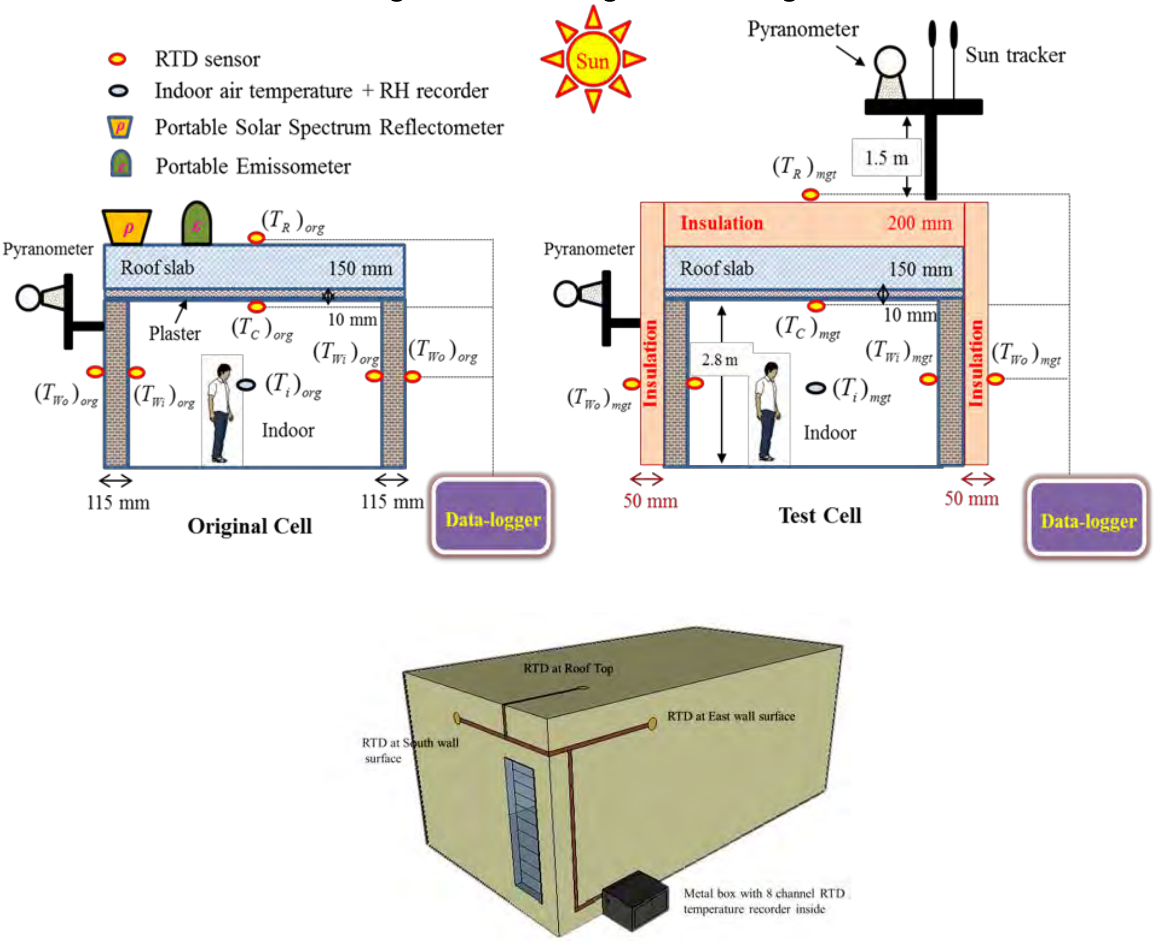


Figure 1: Experimental setup and exterior sensor placements for the Test cell

Modelling and Simulation

Google Sketch-Up Pro and Open Studio Plugin was used to develop a 3D model of the Hall of Residence – 4 as seen in Figure 2 to run simulations using Energy Plus. The physical attributes and material assumptions for the models of both cells are described in Table 1, 2 and 3.

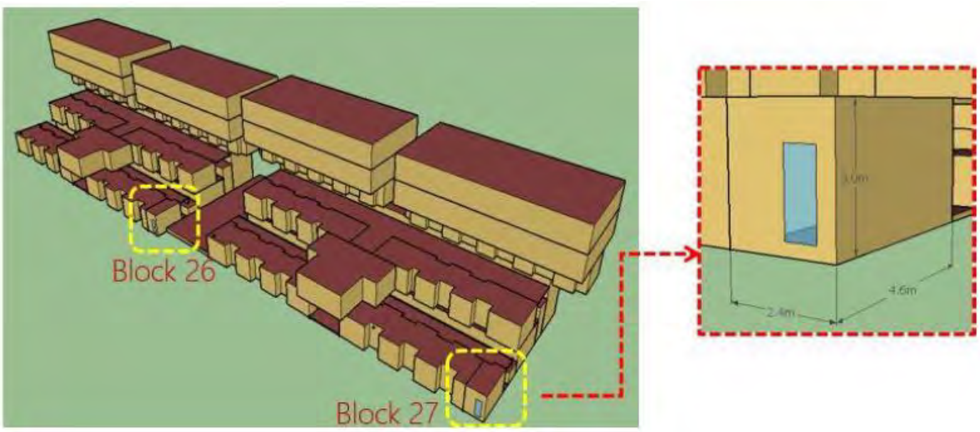


Figure 2: Energy Plus model developed in Google Sketch Up with Open Studio Plug-in

Table 1: Input Assumptions for Energy Plus Model

Inputs for Energy Plus Model	
Location	Singapore
Latitude and longitude	1.39°N and 103.9°E
Elevation	35 m
South and East facing wall area	7.2 m^2
North and West facing wall area	13.8 m^2
Roof surface area	11 m^2
Terrain	Urban
Air-conditioning system	Unitary System (Single coil) On/Off
Indoor set temperature	24°C
Cooling capacity	2.5 kW
COP	3.5
Power consumption	0.75 kW
Occupancy	1

Table 2: Input for building materials for Energy Simulation

Building Materials

Parameters	Block 26- “Original” cell*	Block 27- “Test” cell	Conduction Resistance (m^2K)/W
Walls	Concrete block (150 mm) + Gypsum Plaster layer (12 mm)	External Insulation (50 mm)+ Concrete block (150 mm) + Gypsum Plaster layer (12 mm)	0.40*/1.43
Roof	Concrete slab (150 mm) + Plaster (12 mm)	External Insulation (200 mm) + Concrete block (150 mm) + Gypsum Plaster layer (12 mm)	0.46*/ 4.55
Windows	Double Glazed units (3mm +13mm air+ 3mm)	Double Glazed units (3mm +13mm air+ 3mm)	1
Floor	Concrete Block (300 mm) + Acoustic Tiles (20 mm)	Concrete Block (300 mm) + Acoustic Tiles (20 mm)	0.85
Doors	Wood (30 mm)	Wood (30 mm)	1.5

Table 3: Input for Building Material Properties

Material Properties	Original Cell	Test Cell
Thickness (m)	0.15	0.05
Conductivity (W/m.K)	0.49	0.03
Density (kg/m^3)	512	43
Specific Heat (J/kg.K)	880	1210
Thermal Absorptance	0.9	0.9
Solar Absorptance	0.7	0.6

Calibration

The computational models developed for energy simulations were calibrated using the data opbtained from the site. This was done to predict the impact of insulation on the cooling energy demand and associated energy consumption. Temperature and weather data collected from the live test site was compared to the data set obtained from National Environmental Agency’s (NEA) Climate Research Centre in Singapore. To ensure accuracy, two parameters were compared, namely outdoor air temperature and total solar radiation. This process helped to narrow down days with similar weather profiles to precede the calibration of the model by comparing roof and ceiling surface temperatures of in the measured and computationally simulated data sets. The deviation between the two data sets was found to be between ±5% as seen in Figure 3. Since the infiltration rate of the test site was unknown, after a few simulation permutations, it was found that an infiltration rate of 0.90 air changes per hour (ACH) was the best match between the two data sets with errors within 5%. The calibrated model was used to quantify the annual heat gain, annual heat loss, net heat gain reduction and to subsequently quantify the energy saving potential.

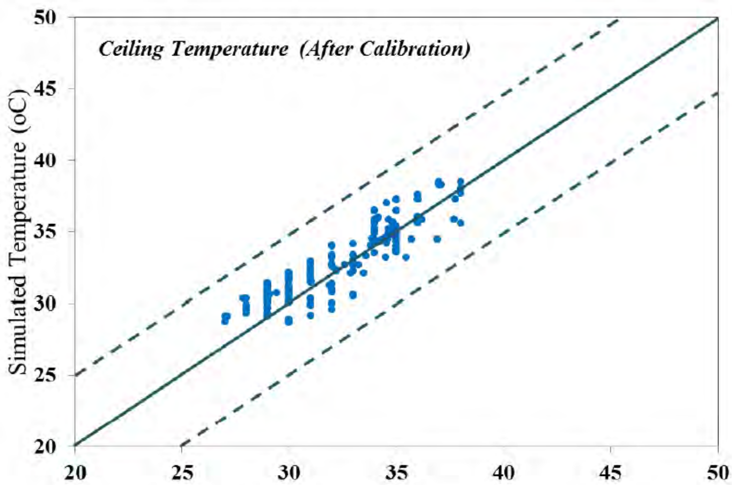


Figure 3: Comparison of computationally simulated temperatures (after calibration) against measured temperatures for ceiling (Zingre, 2016)

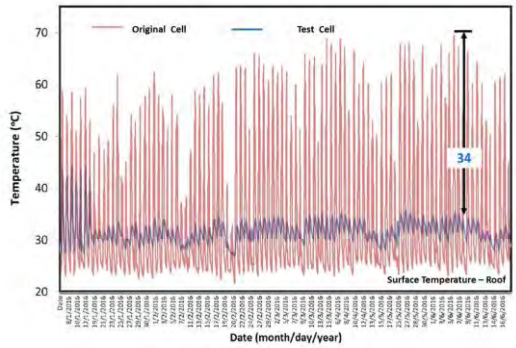
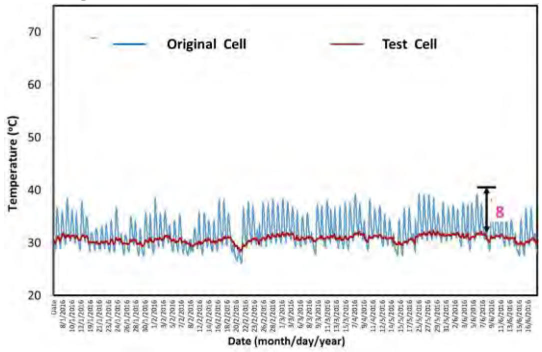
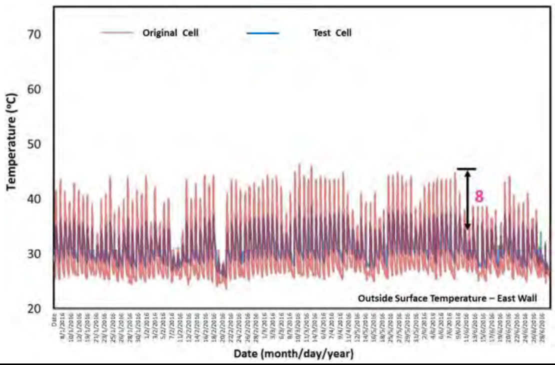
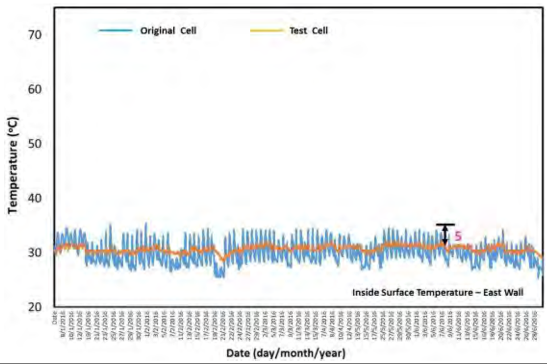
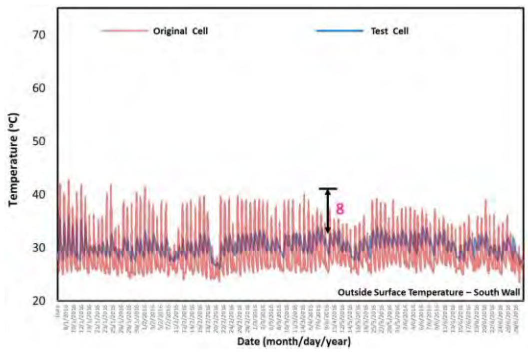
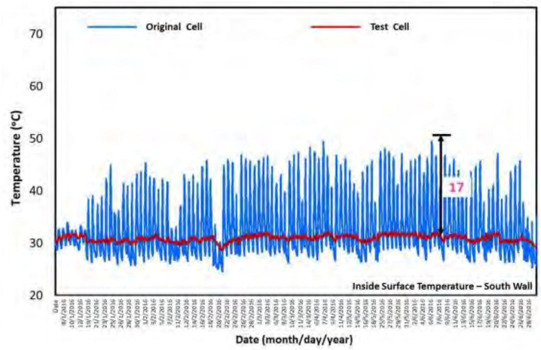
Results and Discussions

Table 4 shows the comparative results collected on site for the two test cells as well as the differences in the indoor air temperature. Figure 4 shows the results of indoor air temperatures from the measurements collected from the site and Figure 5 shows the rests of annual heat gain, loss and net heat transfer from the computational simulation.

External Surfaces

It was observed that the external surface temperature profiles for both units are quite repetitive with higher fluctuations for the surfaces of the Test cell with insulation. This has occurred due to an enhanced thermal resistance of the surfaces with the addition of insulating material of varying thickness. During the daytime, due to the higher thermal resistance of insulating material resulting there is a lesser degree of heat penetration towards the interior of the surface. The peak-time external surface temperatures of the test cell could be higher than the original cell with a delta of 34°C for roofs on a hot day as seen in Table 4. However, during the night-time, a reverse phenomenon occurs i.e., the surface temperature of the Test cell becomes cooler than that of the Original cell. This happens due to the fact that the external surfaces emit more heat to the outdoor environment because of the temperature difference between the surface and the outdoor air at night.

Table 4: Result for External and Internal Surfaces from Measured Data on Site

External Surface Temperature	Internal Surface Temperature
Roof 	Ceiling 
East Wall 	East Wall 
South Wall 	South Wall 

Internal Surfaces

As observed from the results, the interior surface temperature of the test cell is more stable with less fluctuation as compared to the observations made for the external surface. During the day, the internal surface temperatures of the Test cell remain cooler compared to the Original cell by up to 5°C as seen in Table 4. However, during the night, a reverse phenomenon occurred i.e., the internal surface temperature of the Test cell remain hotter as compared to that of the Original cell. This happens due to the fact that the insulating material prevents the outward flow of heat transfer across through the surfaces of the Test Cell, resulting in less increase in the indoor air temperature by the virtue of radiation through the warmer internal surfaces.

Indoor Air Temperature

It has been observed that the overall peak time, indoor air temperatures of the Test Cell had been lower by up to 4.6°C as compared to the original cell as seen in figure 4. However, during night time, the indoor air temperatures of the Original unit were cooler due to the virtue of higher heat emission rate through the envelope (roof and walls).

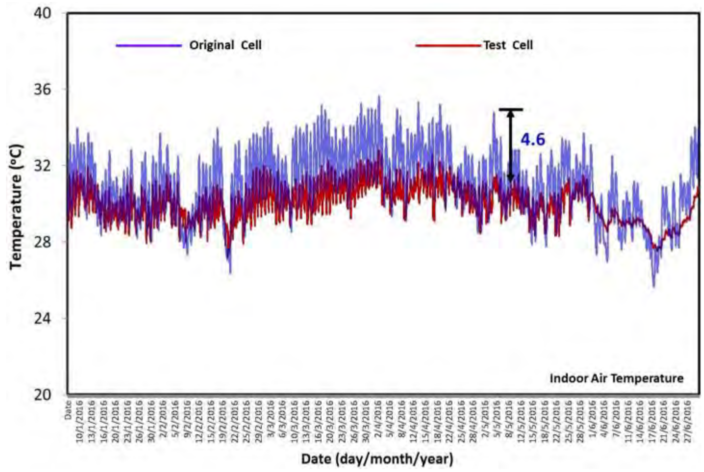


Figure 4: Results for Indoor Air Temperature

Annual Heat Gain, Heat Loss and Net Heat Transfer

In order to quantify the annual heat gain, loss and net transfer the external and internal surface temperatures were considered. The simulation results that were obtained using Energy Plus illustrated, the Test cell provides a significant reduction in the annual heat gain (inward heat transfer during the day time), annual heat loss (outward heat transfer during the night time) and annual net heat gain (summation of inward and outward heat transfer through the day). The computational results suggest that the insulated material was responsible for a significant reduction in the annual heat gain as well as annual net heat gain of 84% and 74% respectively. It was also found that the insulation material was capable of reducing the total building heat gain by 68% and the net heat gain by 39% as seen in figure 5.

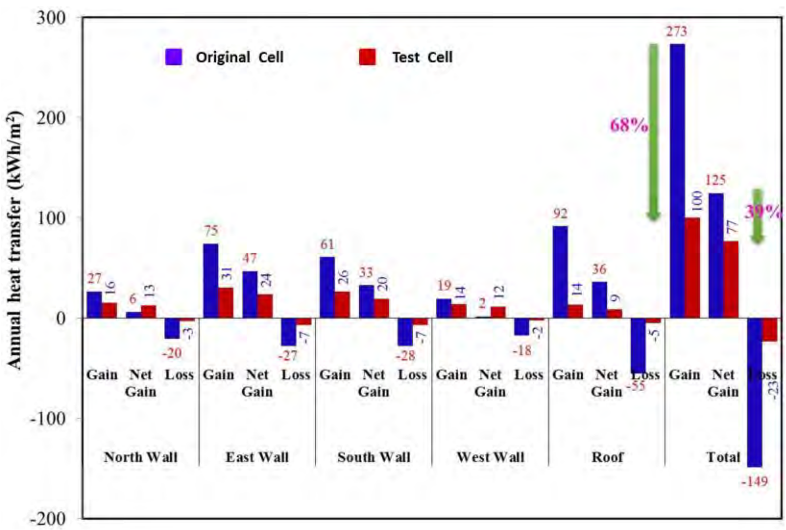


Figure 5: Annual Heat Gain, Heat Loss and Net Heat Transfer

Conclusions and Recommendations

This study investigated the impact of new generation cement based external insulation on traditional reinforced cement concrete construction of a naturally ventilated building in the equatorial tropics. The insulation significantly reduced total building and net heat gains, i.e. the insulation material absorbed more heat during the day, and released less heat at night as compared to uninsulated reinforced concrete structure.

As understood naturally ventilated buildings are design to provide thermal comfort to its occupants without the need of any energy systems for ventilation purpose. Therefore, insulating these buildings would logically not have a direct impact on energy consumption. However, insulating naturally ventilated buildings would reduce the indoor air temperatures in tropical climates, which has a significant impact on the key parameters of occupant's thermal comfort condition. The results also show that there is a considerable reduction in the heat loss (outward movement of internal surface temperatures) by virtue of the insulation material; it is possible to save energy for buildings designed with ACMV systems. A forthcoming paper will soon present the insulation material energy saving potential for such energy intensive buildings in Singapore.

Acknowledgements

We would like to acknowledge Mr. Tomas Krcula, Mr. Tony Renyard and Magortherm for funding this project as well as providing the insulation material for testing. Acknowledgement is also extended to ODFM (Office of Development & Facility Management, NTU) and OAHS (Office of Auxiliary and Housing Services, NTU) for providing testing facility. The entire SSBT team at ERIAN including, Mr. Kishore T. Zingre and Ms. Hansika Gamage who worked on various aspects of measurements and energy simulations. We acknowledge the support lend to us by Mr. Yann Grynberg, Program Director of SSBT at ERIAN & Mr. Nilesh Y. Jadhav, Program Director of Eco- Campus Initiative, NTU and his team who helped in realising this project from the inception. Finally, we thank Prof Werner Lang, Technical University of Munich for providing technical insights on the paper.

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Design to Thrive

Innovative Design and Technical Feasibility of a Low Operation and Maintenance Cost Dwelling Prototype for Immigrants in a Consolidated Urban Area in Santiago de Chile

Gabriela Armijo Plaza[1], Flavia Figueroa Morales[2], Geraldine Jiménez Ponce[3], Paulina Araneda Ijerra[4], Leticia Roubelat Marques[5], Oscar Godoy Cruz[6]

[1] Director of Bioclimatic Laboratory, Faculty of Architecture, Urbanism and Landscape, Universidad Central de Chile, Santiago, Chile, gabyarmijo@ambiente.cl
[2] Student, Faculty of Architecture, Urbanism and Landscape, Universidad Central de Chile, Santiago, Chile, flavia.figueroa@live.cl
[3] Student, Faculty of Architecture, Urbanism and Landscape, Universidad Central de Chile, Santiago, Chile, geraldine.jp@live.cl
[4] Student, Faculty of Architecture, Urbanism and Landscape, Universidad Central de Chile, Santiago, Chile, pauli90chile@hotmail.com
[5] Researcher, Bioclimatic Laboratory, Faculty of Architecture, urbanism and Landscape, Universidad Central de Chile, Santiago, Chile, leticiaroubelat@hotmail.com
[6] Professor, Faculty of Architecture, Urbanism and Landscape, Universidad Central de Chile, Santiago, Chile, oscar.godoy@ucentral.cl

Abstract: The "Tendal" prototype exposed emerges from the participation of a team of undergraduate students and lecturers in the "Construye Solar" contest organized by the NGO Solar Route, the Ministry of Housing and Urbanism, and the Ministry of Environment of Chile. Its goal is the development of sustainable housing, orientated to vulnerable environment families. In the last decade, an intense flow of foreign immigrants has arrived in Chile. Currently, there is a disproportionate concentration of foreign population in central areas and precarious access to comfortable and good-quality housing. Public housing is located in the city periphery, which implies a high rate of emitted CO2 and airborne pollution caused by transportation needs. The question that arises is: What are the current needs of social housing in Chile, particularly for immigrants? This article aims to expose the urban, constructive, architectural and socio-technical feasibility of building blocks with low operation and maintenance costs. Universal accessibility, floor areas and cost regulations where given by the contest rules. An innovative solar clothes dryer to prevent indoor humidity is proposed. Environmental performance simulations where made. The prototype is under construction for being tested on May 2017 during the contest.

Keywords: mixed use, solar dryer, migrants housing, innovative prototype, low footprint.

Introduction

The "Construye Solar" competition is a challenge organized by the NGO Solar Route, the Ministry of Housing and Urbanism and the Ministry of Environment of Chile. It invites universities of Chile and world to develop a sustainable public family house prototype, in order to change and improve their environmental quality and construction technologies.

Full scale prototypes are built to be shown in an open public exhibition. They will also be evaluated on the basis of their energy efficiency, comfort and sustainability, among other aspects (http://www.construyesolar.com/el-proyecto/). Through its demands, the contest constitutes itself as an instrument that enhances sustainability inclusion in the academic and professional fields. This concept encompasses design, construction, operation and maintenance of dwellings.

The “Tendal” prototype exposed in this paper emerges from the participation of a team of undergraduate students and lecturers of the Central University of Chile in the "Construye Solar" contest. This article aims to expose the urban, constructive, architectural and socio-technical feasibility of building low rise blocks with low operation and maintenance costs. This residential building is aimed at the immigrant community and located in a consolidated urban area of Santiago Centro District. There are regulations given by the contest such as: universal accessibility, maximum floor areas and cost which were all taken into account. The team decided to design a multilevel building block complex. This was due to the fact that detached housing typology is not an adequate solution for achieving neither urban, nor environmental high standards, given their high area to volume ratio and low land use efficiency. Besides (PLEA, 2012; CIBWBC, 2013), up to date, few examples of sustainable residential buildings exist in Chile, the majority of them are detached single family dwellings. The prototype is under construction by students and volunteers for being tested next May 2017 during the contest.

Public and Private Housing’s current state: urban and building scale

Santiago´s urban structure and expansion model is based on single use zoning, consisting of purely residential large city areas with no associated infrastructure such as education, convenience stores and workplaces. This fact forces the residents to use motorized transport even for simple everyday tasks. Despite government initiatives intended to improve public transport, both buses and metros continue to be overcrowded and run with no fixed timetable (CIBWBC, 2013). At the same time the policies for achieving social housing targets has led to site selection based on low land value, almost always being located on the city limits. As a consequence, occupants have less on site or proximal work opportunities and incredibly high commuting times associated costs. (CIBWBC, 2013).

In Chile, residential developments and their related services carry on with no significant consideration of sustainability or energy efficiency (PLEA, 2012; CIBWBC, 2013). This results in low habitability standards (IC, 2006), such as low comfort levels in winter and summer, unacceptable indoor air RH and quality levels, all of them causing health difficulties and increasing operational and maintenance costs.

High rates of indoor RH existing in Chilean dwellings deserve special attention, having a major impact on thermal comfort and building pathologies. These rates are intensified in public housing, due to combination of indoor production sources and poor quality construction materials. Among all indoor sources, drying clothes and open flame heaters stand out. They derive and can be prevented through good architectural design practices that involve technical innovation and more restrictive associated regulations.

If clothing is dried within an enclosure (Rivera, 2012), about 10 kg of water vapour per day is released in each family laundry. Mould growth due to condensations in building envelope cause serious health problems. Besides, it implies high maintenance costs and shorter durability of dwelling. As the authors of the guide Welfare Housing: Sustainable

Design Guide for Residential Habitat (U. de Chile et al., 2004) states: “Cloth washing and drying activities should be done outside or in an intermediate private or common space”.

Concerning open flame stoves, its use has extended due to the non-obligation of delivering dwellings with heating system, leaving the users the choice of portable heaters. On the other hand, fuel poverty exists for most of inhabitants of the country. These facts force the population to use open flame heaters and poor quality fuels, a polluting and inefficient heating solution. Cheap fuels used by occupants as Kerosene, LPG, and natural gas produce respectively (Rodriguez, 2009) 2.50, 1.60 and 2.25 kg of water vapour per kg of fuel. The production of indoor humidity increases as a result of the thermally inadequate built envelope because it is necessary to use more fuel to reach comfort temperature levels. Indoor air became very polluted as well.

Immigration’s current state

In the last decade, an intense flow of foreign immigrants has arrived to the country increasing from 1.2% of total population in 2002 to 2.17% in 2012 (INE, 2002; INE, 2012). According to various sources in recent years migration has been characterized by being of Latin American origin, feminine, great ethnic heterogeneity and for being in an active age range (Poblete et al., 2014; INE, 2012; DEM, 2014).

The migratory phenomenon has a tendency to concentrate on certain territories, with a preference for certain cities and within these in particular residential areas (Segura et al., 2014; Poblete et al., 2014). This pattern of settlement, explains itself through the existence of attraction centers expressed through what Segura et al. (2014) calls objective variables for improvement of living conditions. These are the existence of employment sources, high connectivity with central urban areas which also allows jobs access and the existence of a possible housing market for rental or purchase combined with the presence of a primary social network in which the immigrant is inserted.

The Metropolitan Region of Santiago (DEM, 2005-2014) englobes 61.5% of foreign resident total population, the highest percentage of country regions. The capital district that concentrates the most immigrant population is Santiago Centro with 54.4%. This area (Segura et al. 2014) is composed by a system of mixed use neighborhoods with their own identity, where housing and trade coexist. The arrival and concentration of this new collective in the district affects the economic, social and urban morphology of this area. There has been an important neighborhood upgrading in certain areas of Santiago Centro (Segura et al., 2014; Poblete et al., 2014) given by the economic dynamism of immigrants who commonly open new stores and make more dynamic public spaces where they settle.

Within the conditions to foreigner status that must be complied to reside in Chile, housing stands out as the main demand and most vulnerable aspect. They must not only have enough money for renting but also fulfill the requirements to do so. These (Segura et al., 2014) constitute one of the main obstacles to get a house with minimum habitability conditions, and largely restrict their possibilities within the real estate market.

Social sustainability

Based on the studies carried out on the migration phenomenon, it was decided to locate the project in Santiago Centro District: Matta Sur neighbourhood, a working deteriorated area by the abandonment of sheds and warehouses.

The housing project enhances integration by providing immigrants a place of residence through government policies and mixing the migrant-national and foreign population in the same neighbourhood. Objective variables for the improvement of living conditions had to exist: location near city centre, reduced transfer times and distances, presence of services and trade and proximity to employment sources.

Mixed-use residential neighborhoods propose an urban model that emphasizes walkable distances. Motorized transportation is reduced as well as the associated carbon footprint. Strategies based on balancing population density and land-use means a request for urban intensity and active neighbourhoods. Considerations on social, economic and environmental sustainability in design, construction, operation and maintenance stages, helps to improve Nationals' Public Housing standards.

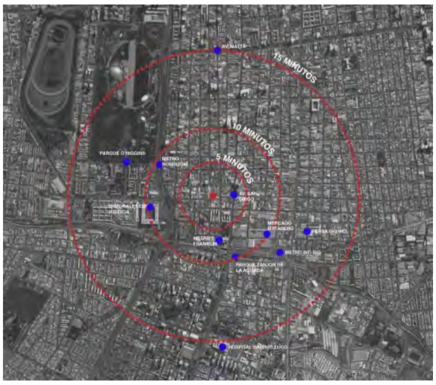


Figure 1. Map of walkable distances from the project site. Figure 2. Housing Complex Image

Locating public housing in a consolidated central urban area and having a mixture of public and private markets helps avoiding socio spatial segregation. Implementing an urban rooftop vegetable garden offers social relation spaces in residential housing, reinforces community strength and social cohesion between neighbors.

The proposed apartment layout is a 59 sq. m. open floor plan with a central core of services and a multiuse walk around arrangement than can create private spaces through sliding doors for different activities. Modular convertible furniture provides a flexible, non hierarquical space. This allows high adaptability to specific needs of immigrant families.

Figure 3. Housing block North façade image

Economical sustainability

Regarding house operation and maintenance, when implementing new technologies would be desirable to have trained tenants to improve certain use habits and to re-enforce their environmental awareness. A manual of active and passive facilities has been made.

When considering economic strategies, the objective is to subsidize the housing complex and the associated equipment with government programmes. A study of the available subsidies has been made, considering among them, one for housing improvement. The house complex will include different values and floor plan apartment typology.

Although renewable energies' implementation is an expensive investment it would reduce operational costs, reflecting these benefits both at personal and public level. The apartment cost, considering construction materials, renewable energy devices, transportation, specialized services and all other costs coming from construction stage reaches $21.000.000 which is the budget allowed for this contest. (aprox. € 30.000)

Environmental sustainability

The project presented is intended for the city of Santiago de Chile. The conceptual design method was Carl Mahoney's, originally orientated to humid tropical climatic zones adapted (Armijo, G. 1974) to be used in other climates such as those existing in Chile.

The climate of Santiago (33º 30´S) has a short and cold winter and a long hot and dry summer, with a mild 15º Celsius annual average. Temperature day and night swings are of 10º to 20º Celsius. This important and differential characteristic leads to design envelope with thermal mass capable to achieve interior moderated peak temperatures. The wind is almost non-existent and rain is about 350 mm per year and only at wintertime.

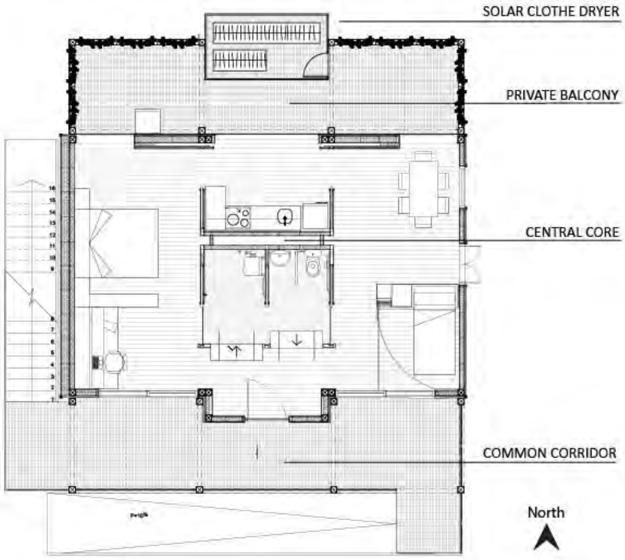


Figure 4. Floor plan"Tendal" housing prototype.

Proper capture of solar energy at block's design is fundamental. After simulations in the equinoxes, solstices at different hours of the day were performed, distance between buildings, shape and dimension of blocks were defined. Good orientation is combined with solar control devices. The single corridor block has its long axis with an east west orientation. The largest façade is facing north - south. In consequence, living spaces are North orientated; access is located South and the facilities in the centre. These facts facilitate cross natural ventilation at summer nights and two-way direction for better daylighting. Central core services are in the most efficient position for facilities and technical services. Balcony floor of galvanized steel grating has double function: outdoor space and semi-transparent solar control device, without blocking air convection. Fully insulated pre-fabricated modules supported by independent steel framed structure with double-glazing and siding with copper impregnated wood, all reduce thermal bridges. The result is a highly efficient dwelling for Chilean standards. The structural system gives the possibility of making light walls with locally certified 120mm sheep wool insulation.

The use of materials with the least possible carbon footprint is considered. Local supplies such as wool and pinewood are chosen. The structural material used is steel, which has a much lower impact than reinforced concrete. Steel can be recycled indefinitely and allows easy assembly and disassembly, turning it into a suitable material for prototype production. Healthy materials are also used, as cooper treated wood frames and exterior façade.

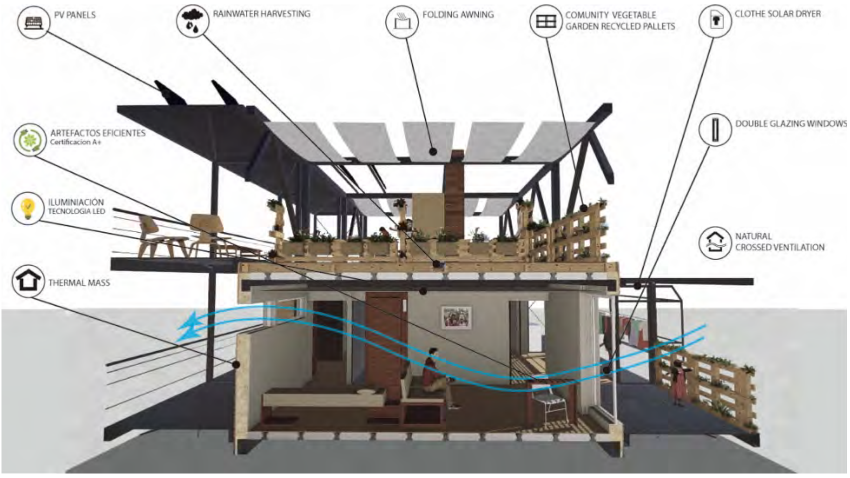
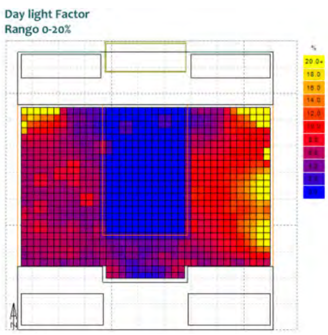
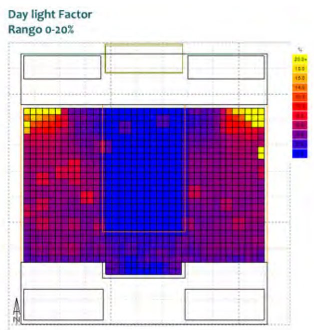


Figure 5. “Tendal” Prototype and community rooftop section.

Apartment’s analysis of daylight availability, sun path simulation and Daylight Factor analysis were carried out. Size and location of windows in all four different orientations were defined. Also shape, dimension, layout and solar protections where settled. Design principle of daylighting was light capture coming from north and south. This is associated with summer overheating protection with balconies. Windows principal target it to seek good light distribution, considering the interior furniture space variations.

It is possible to conclude through simulations that the strategies proposed to generate better natural lighting and thermal gain through the radiation improve substantially by incorporating steel grating as the material of corridors and balconies. This allows solar radiation during winter. On the contrary in summer a mobile solar protection is devised in the north balconies.





Figures 6, Daylight factor analysis: favourable apartment case, north, south and east windows.
Figure 7.Daylight factor analysis: unfavourable apartment case, north and south windows.

The solar clothes dryer is a small polycarbonate room attached to the steel frame at north balcony. It has openings at the floor and at the upper front creating natural convective flow. In addition it has a small movable PV to energize a small fan to improve airflow at cold season. It substantially diminishes indoor humidity production, improving hydrothermal comfort and gives an appropriate technical solution.

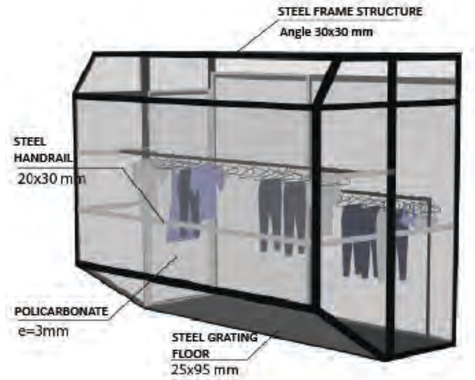


Figure 8. Solar clothes dryer design. Figure 9. Team photo: solar clothes dryer integrated in the prototypes terrace.

Cross ventilation strategy combined with a controlled ventilation system with heat recovery contributes to a good indoor air quality. Natural ventilation should be used in summer mainly at night, periods in which the outside temperature is within the range of comfort (18 to 24 ° C). During winter at cold hours, there is a need of renewing air without opening windows. A heat recovery air to air exchanger will be implemented to reduce the CO2 concentration inside, associated with a CO2 sensor.

Strategies for efficient water use are as follows: economical and efficient faucets and artefacts use and establishing housing energy saving behaviours for occupants at user´s manual. For the housing block wastewater treatment (grey and black waters) the "Tohá System ®" is proposed to be installed. Is a Chilean technology created by Dr. J. Tohá in the University of Chile's Laboratory. The system is also named as Dynamic Aerobic Biofilter.

For hot water supply an electric water heater with integrated heat pump is installed, storing 270 litres at 45°C with COP 4.3. For optimal efficiency, a programme establishing a timetable for its use is settled. The appliance should be working during the day, so the energy comes from the PV panels. During night time water is kept hot with no need for electricity with a minimal loss.

Heating peak demand occurs in August 1st at 6:00 hours, when 2098 watts are needed to keep 19°C. The interior temperature is within comfort parameters range (18 -25 °C) through the entire analysis. A 2 kW convective radiator produces enough energy to cover the demand corresponding to the most unfavourable moment of the year.

The PV panels are located in the rooftop´s steel structure. The on-grid system feeds electrical apartments demand, but energy taken by the grid is valuated only 60% of the regular tariff. As a consequence electrical appliances should be used in daytime so the electricity is provided by the panels. The heat-pump consumes 0.6 Kw and for a 150 liter daily demand 4.8 operation hours are needed. This situation is satisfied between September and April and partially between May and August. Between October and March there would be a surplus for consumption.

Conclusions

Supportive, inclusive mixed and dense house prototype is achieved. As the project is founded in the migration phenomena a sensible design of 4 levels blocks with moderate density is proposed. It is a mixed-use, modular, collective block. It is situated within the deteriorated city centre connecting houses to urban centres, services and jobs. Open plan apartments are flexible for housing different family groups. Vegetable gardens are located at a portion of shaded rooftop for community work and in private balconies for families.

Environmental strategies for Santiago are adopted with design decisions for design for Mediterranean climate. These are: single corridor block with main facade and private balcony facing north; Solar clothes dryer and space for gardening; translucent corridor so light can pass through and envelope U values 21 % of standard Chilean Regulations.

Clothes solar dryer substantially diminishes indoor humidity production, improving hydrothermal comfort and gives an appropriate technical solution.

The construction of this residential building prototype is technically feasible with the current local resources, technologies, knowledge and construction related professionals, with no air pollution emission and with much lower environmental footprint.

At the contest, Tendal prototype won the first prizes in Sustainability, House Comfort Performance (monitoring) and Water Usage; Second prize in Architecture and Urban Design ; third prize in Innovation and Interior Functionality.

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The Use of Passive Cooling System for SME Hotel Renovation

Kawin Preechawuttidej[1] and Pattaranan Takkanon[2]

[1] Master of Architecture (Building Innovation), Kasetsart University, Bangkok, Thailand, kawinisoe@gmail.com
[2] Department of Building Innovation, Faculty of Architecture, Kasetsart University, Bangkok, Thailand, pattaranan.t@ku.th

Abstract: Shophouse is the most common building type in Thailand, this type is increasingly popular for small-to-medium enterprise (SME) hotel business. Shophouses have been renovated to be hostels these days. Nonetheless, most of them are closed areas and rely on air conditioning system. The research aims to promote natural ventilation and combine passive cooling techniques for solving problems and saving energy. The experiments are divided into 2 series: 1) CFD simulation to test effects of opening positions and sizes for cross and stack ventilation; 2) Thermal simulation to select case from the first series, then test effects of double roof and night ventilation. Results from the first series show that the best case in terms of air flow rate and wind distribution is the plan with 1.50 meter wide both inlet and outlet which are not in line with the staircase. Average wind speeds range from 1.4 to 2.1 m/s which promote occupants' thermal comfort in a common area. Results from the second series show that night flush is more effective than having double roof especially during the night in winter as the average temperature reduction is 2.4°C. This can alleviate overheating condition in closed area of a guest room.

Keywords: Hostel, Shophouse, CFD (Computational Fluid Dynamics), Passive cooling, Sustainable architecture

Introduction

Hostel is becoming popular in Bangkok and other scenery towns. Thailand is located in hot-humid climatic region experiencing high air temperature and relative humidity. It is more feasible to use passive cooling techniques to provide comfort in shophouse that is renovated to be an SME hotel. The passive design approach might also suit travellers' behaviour better than active design approach since they prefer to spend time outside.

Passive cooling

Passive cooling techniques are part of passive design approach which aim to transfer heat from its sources to sinks such as the sky or water without using electrical equipment (Givoni, 1994). An example of adaptive reused space of a tropical shophouse which is unnecessary for active cooling can be found in Penang as shown in Figure 1 (Omar et al, 2011).

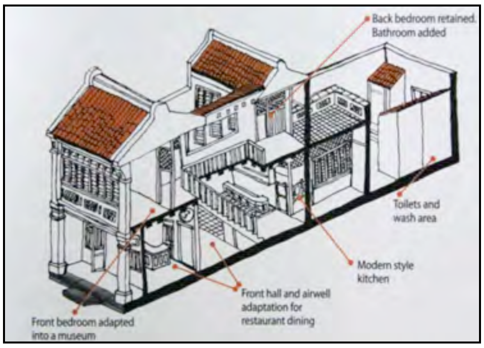

Figure 1. Penang traditional shophouse

This traditional building adopted many techniques including stack ventilation, night flushing and buffer zone to prevent and reduce heat.

Ventilation

A suggestion is the staircase should be in the middle of the shophouse as an atrium for stack ventilation (Prasongsamrit, 2016).

Figure 2. Staircase in the middle

Comfort zone

Cooling effect from air movement can be calculated from equation 1 (Szokolay, 2004).

$$dT = 6\ v_{eff} - 1.6\ v_{eff}^{2} \qquad \text{.....eq.1)}$$

Where v_{eff} is Effective velocity $= v - 0.2$
and neutral temperature can be calculated from equation 2 (Auliciems, 1981).

$$T_n = 17.6 + 0.31\ T_{av} \qquad \text{.....eq.2)}$$

Where T_n = Neutral temperature, °C
T_{av} = Mean monthly outdoor temperature
Then upper comfort limit is T_n + 2.5°C and lower comfort limit is T_n - 2.5°C.

Methodology

The present work starts with field survey to find a typical shophouse hostel. Then using computer simulations, the first series to analyse CFD in the case study building by considering airflow characteristics and velocities. The second series is conducted by adding other strategies from the first series and analysing thermal condition. Finally, appropriate design guidelines will be proposed.

Field work

The field survey involves 10 samples of renovated shophouse hostels nearby the airport link terminal. The methods include questionnaire survey, taking photos and measurement work.

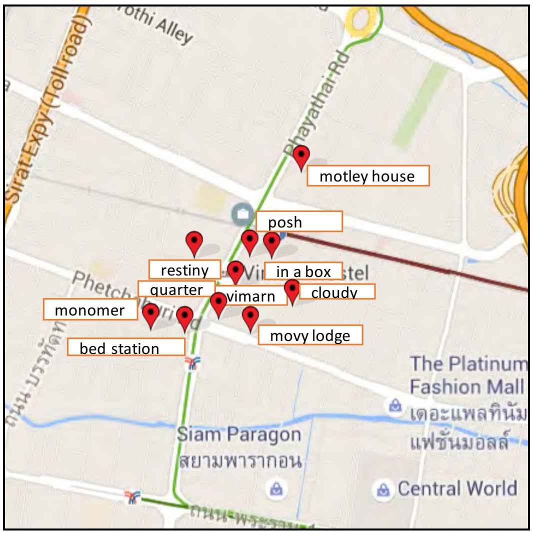

Figure 3. Hostels surveying

Typical plans for simulation

There are 13 possible plans for the study. Their design variables are opening location and opening size that comply with building regulation. Base case has inlet on the first floor and outlet at stair ceiling as it is the common design. Set A has additional inlets on the second and the third floors and set B has additional outlets at the back of the building.

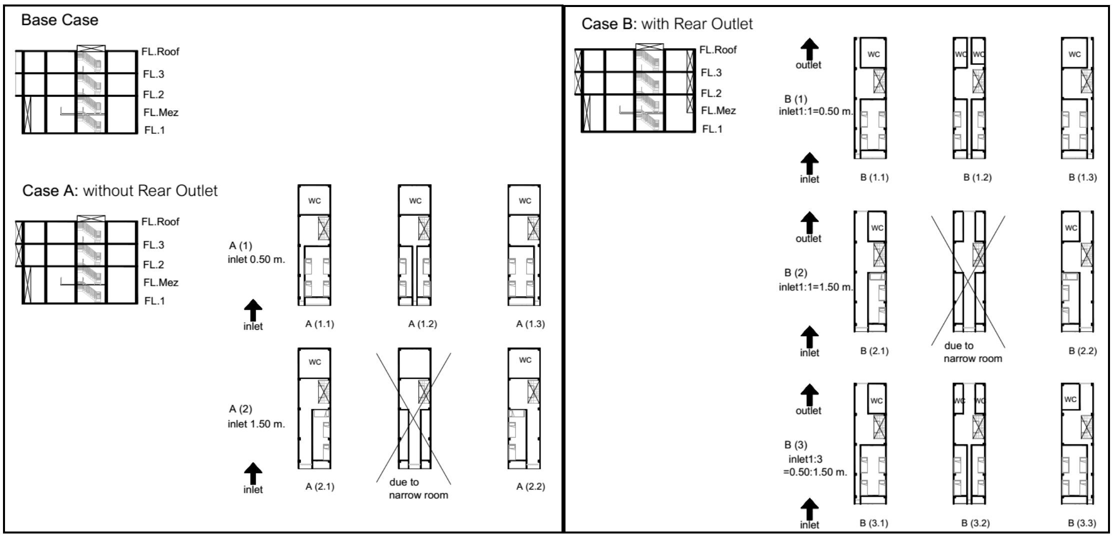

Figure 4. All cases of 13 different plans

CFD Simulation

According to the weather data of Bangkok, an hourly average of wind velocity for the whole year is 1.15 m/s. Frequency of wind velocity ranging from 1 - 1.5 m/s is the biggest as it takes 28.3% of all. Therefore, this study uses 1.2 m/s for the experiment. In each case, indoor air velocities are measured at 14 measurement points locating on plane X and Z in common areas.

Figure 5. Measurement points

Table 1. CFD result shows velocities on measurement points all cases

	@v=1.2	X1	X2	X3	X4	X5	X6	X7	X8	Z1	Z2	Z3	Z4	Z5	Z6
0	**base**	0.6	0.17	1.08	0.49	3.56	0.21	2.72	0.23	0.69	0.21	0.63	0.93	3.41	3.31
1	**A (1.1)**	0.28	0.11	0.67	0.44	2.53	0.35	3.09	0.44	0.47	0.15	0.3	0.62	2.5	2.7
2	**A (1.2)**	0.19	0.15	0.72	0.47	2.01	0.12	1.77	0.22	0.53	0.01	0.1	0.55	2.33	1.59
3	**A (1.3)**	1.7	0.21	0.71	0.45	2.24	0.21	1.94	0.45	0.53	0.15	0.24	0.61	2.44	2.68
4	**A (2.1)**	0.13	0.17	0.46	0.43	1.82	0.62	2.66	2	0.26	0.18	0.1	0.5	1.79	2.38
5	**A (2.2)**	0.15	0.19	0.57	0.53	1.56	0.12	1.89	0.38	0.11	0.23	0.23	0.5	1.72	2.31
6	**B (1.1)**	1.6	1.42	1.9	1.77	0.64	0.8	1.55	0.76	1.65	1.27	1.52	1.6	2.13	2.34
7	**B (1.2)**	1.5	1.43	1.7	1.76	1.11	0.24	1.27	0.27	1.71	1.09	1.49	1.67	1.68	1.13
8	**B (1.3)**	1.43	1.5	1.77	1.78	1.6	0.48	1.53	0.55	1.7	1.18	1.53	1.69	1.91	1.71
9	**B (2.1)**	1.71	1.32	1.69	1.56	0.83	2.13	1.31	2.3	1.52	1.08	1.34	1.47	2.01	2.17
10	**B (2.2)**	1.32	1.27	1.42	1.56	1.86	0.46	1.94	0.33	1.49	0.92	1.26	1.43	1.93	1.61
11	**B (3.1)**	1.38	1.6	1.77	1.71	1.82	0.92	1.17	1.3	1.85	1.09	1.36	1.76	2.72	2.61
12	**B (3.2)**	1.56	1.48	1.94	1.81	1.78	0.37	1.16	0.58	1.7	1.16	1.52	1.64	2.18	0.96
13	**B (3.3)**	1.48	1.45	1.81	1.85	1.7	0.5	1.24	0.48	1.72	1.28	1.46	1.56	2.66	1.61

Figure 6 presents indoor air velocities at measurement points of all cases. Data from the table can generate two graphs showing velocities on the sectional planes, 8 points on plane X and 6 points on plane Z.

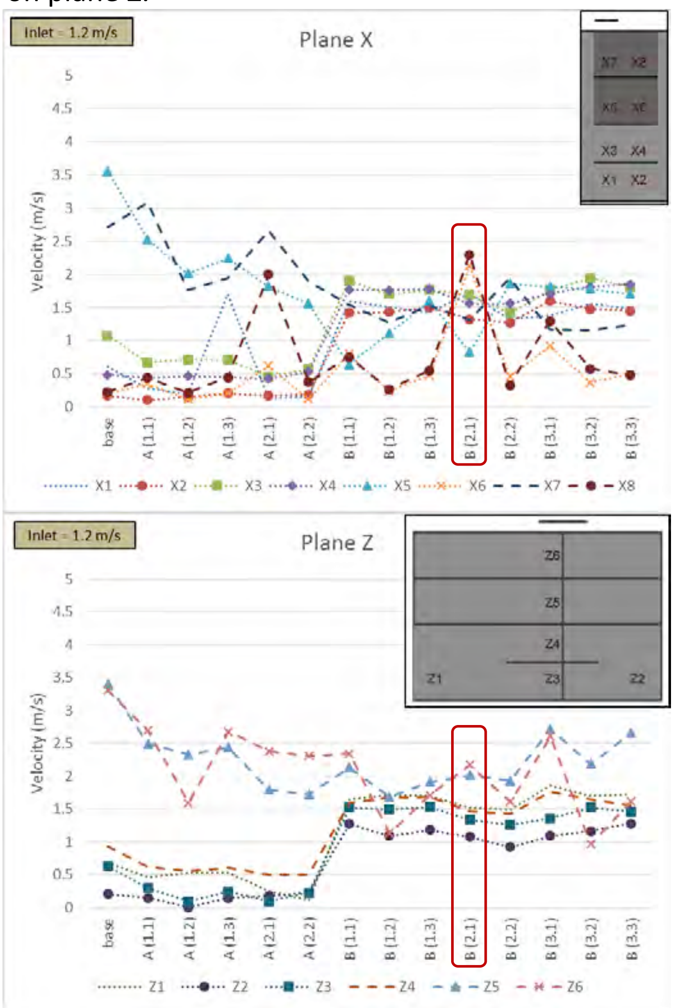

Figure 6. Graph shows indoor velocities

Plane X shows that Case 2.1 of set B gives the highest velocities significantly due to the opposition of inlet and outlet and they are not in line with the staircase. On plane Z, Case 3.1 of set B shows velocities (Z4, Z5 and Z6) much higher than others but there are some points showing low velocities (Z2 and Z3). When considering all 14 points on both plane X and Z which are common areas, Case 2.1 of set B shows the best level of wind distribution consistency and high average wind speed ranging from 1.4 - 2.1 m/s.

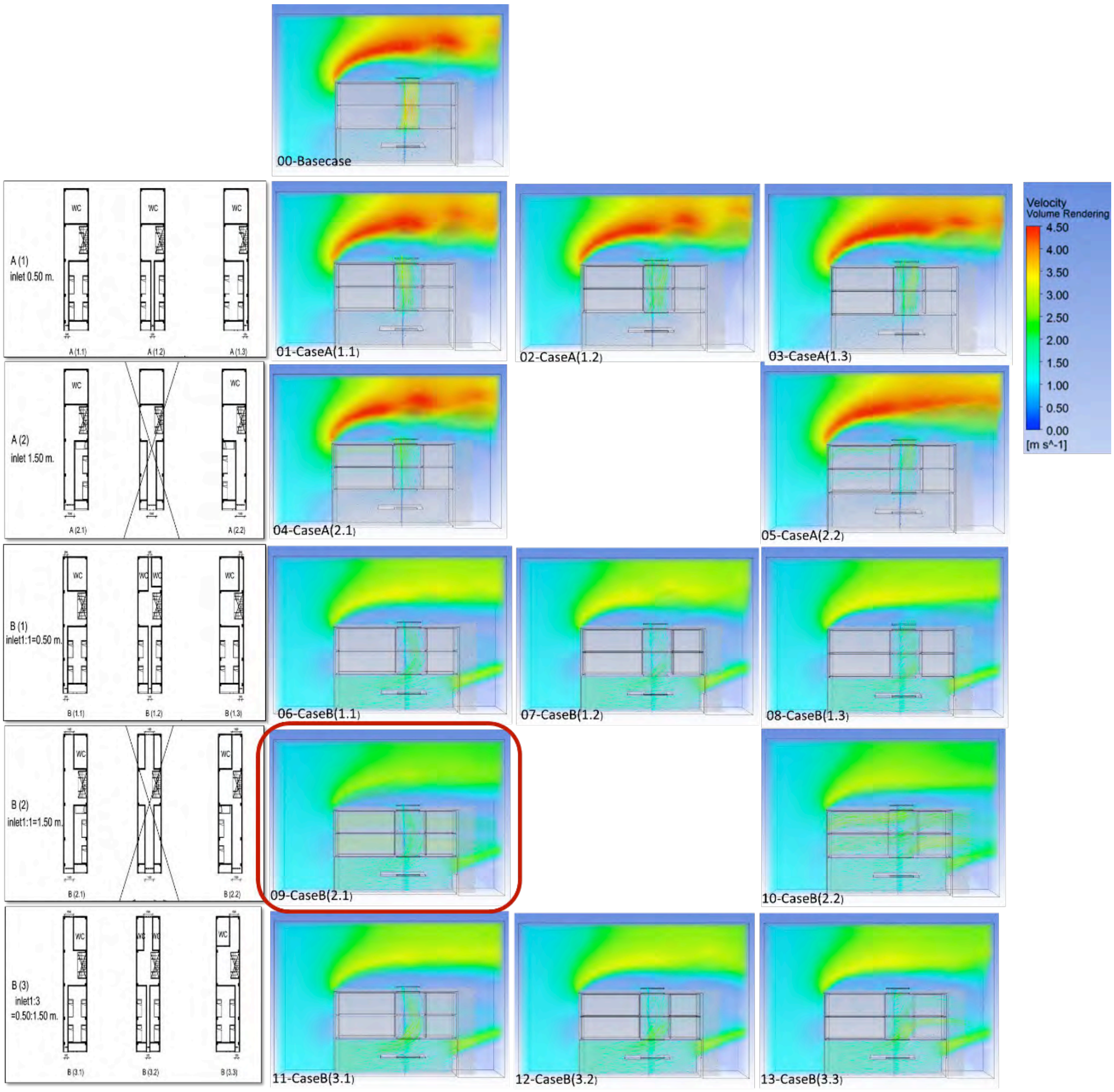

Figure 7. Airflow comparison by colour contour

Figure 7 shows the difference between each case by colour contour. All cases of set A show very high wind velocities (red) about 4.5 m/s at the front top and very low speed (dark blue) at the first floor inlet. Every case of set B with outlets can promote more wind (light blue). However, Case 2.1 of set B, in particular, has the lowest rate of fluctuation.

Thermal simulation

Taking Case 2.1 of B as the best case from previous experiment as it gives highest indoor air velocities by average, this part is aimed to further study other passive design strategies including double roof and night ventilation. The cases for comparison are base case, case 1 with double roof, case 2 with night ventilation (8pm-8am), and case 3 which is the combination of case 1 and 2. Results show that winter season has better efficiency than summer and rainy season because the very low temperatures at night have an impact when opening the building during the night. Besides, double roof gives small temperature reduction in every season.

Table 2. Overall comparison of difference

°C	Double roof	Night flush	Combine
Winter	0.35	2.40	2.70
Summer	0.39	1.32	1.64
Rainy	0.11	1.21	1.30

Since winter shows biggest differences, its results are analysed in terms of indoor air temperatures as shown in Figure 8.

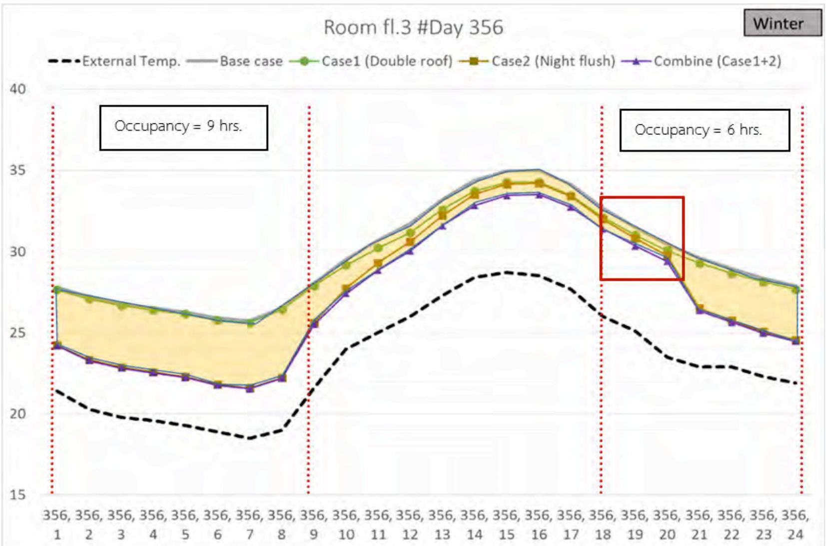

Figure 8. Graph shows air temperature in winter

Table 3. Temperature different between addition strategies and base case in winter

Winter	Hour	External	Base case	Case1 (Double roof)		Case2 (Night flush)		Combine (Case1+2	
Resultant Temp.	356, 1	21.4	27.8	27.65	0.15	24.25	3.55	24.19	3.61
	356, 2	20.3	27.22	27.08	0.14	23.34	3.88	23.28	3.94
	356, 3	19.8	26.81	26.67	0.14	22.87	3.94	22.82	3.99
	356, 4	19.6	26.52	26.39	0.13	22.58	3.94	22.52	4.00
	356, 5	19.3	26.28	26.16	0.12	22.29	3.99	22.24	4.04
	356, 6	18.9	25.89	25.77	0.12	21.82	4.07	21.76	4.13
	356, 7	18.5	25.74	25.62	0.12	21.59	4.15	21.54	4.20
	356, 8	19	26.54	26.43	0.11	22.23	4.31	22.19	4.35
	356, 9	21.6	28.05	27.89	0.16	25.61	2.44	25.49	2.56
	356, 10	24	29.49	29.17	0.32	27.73	1.76	27.42	2.07
	356, 11	25	30.7	30.22	0.48	29.32	1.38	28.85	1.85
	356, 12	26	31.73	31.17	0.56	30.6	1.13	30.04	1.69
	356, 13	27.3	33.2	32.58	0.62	32.21	0.99	31.59	1.61
	356, 14	28.4	34.39	33.73	0.66	33.51	0.88	32.84	1.55
	356, 15	28.7	34.96	34.26	0.70	34.14	0.82	33.45	1.51
	356, 16	28.5	34.98	34.28	0.70	34.21	0.77	33.52	1.46
	356, 17	27.7	34.12	33.45	0.67	33.39	0.73	32.73	1.39
	356, 18	26	32.68	32.1	0.58	31.98	0.70	31.4	1.28
	356, 19	25.1	31.49	31.01	0.48	30.81	0.68	30.34	1.15
	356, 20	23.5	30.44	30.06	0.38	29.77	0.67	29.39	1.05
	356, 21	22.9	29.61	29.29	0.32	26.53	3.08	26.35	3.26
	356, 22	22.9	28.93	28.66	0.27	25.77	3.16	25.65	3.28
	356, 23	22.3	28.35	28.12	0.23	25.07	3.28	24.97	3.38
	356, 24	21.9	27.87	27.66	0.21	24.55	3.32	24.47	3.40
	Temperature diff. from Base case (Hourly)				0.35		2.40		2.70

This table shows the different temperatures from 4 cases. Case 2 (night flush) is very effective since it can reduce air temperature by 2.4°C on the coldest day of the year while Case 1 (double roof) is not obviously effective.

Analysis

The result from Case 2.1 of set B shows that an average velocity from 14 measurement points is 1.60 m/s when velocity at inlet is 1.20 m/s and the cooling effect can then be calculated from equation 1.

$$dT = 6\,(1.6-0.2) - 1.6\,(1.6-0.2)^2 = 5.26°C$$

When the mean temperature (T_{av}) of every month in Bangkok is 29.3°C. Therefore, the neutral temperature can be calculated from equation 2.

$$T_n = 17.6 + 0.31(29.3) = 26.7°C$$

The upper comfort limit becomes 26.7+2.5 = 29.2°C. With the cooling effect from air movement, the comfort limit can be extended by adding dT, thus, 29.2+5.26 = 34.46°C.

Design guidelines

Ventilative cooling

From the results of all cases, it can be concluded that openings for cross ventilation can provide consistent wind distribution when the openings at the front and the back of the shophouse are not in line with the staircase. The minimum opening width for inlet should be 1 meter and it could be located in corridor axis to gain more wind.

Nocturnal ventilation

For further strategies, operational time can be controlled by occupants. During the night, opening windows for night ventilation is recommended.

Using double roof

To use double roof, there should be no obstruction for the wind which can trap the heat. However, using double roof alone is not effective to control internal heat.

Further suggestion

It is recommended to use insulation above the ceiling to prevent incoming heat and fan could be used to enhance cooling effect, thus bringing the indoor condition down to the comfort level (Takkanon, 2006). Plants can also help prevent dust and improve micro-climate.

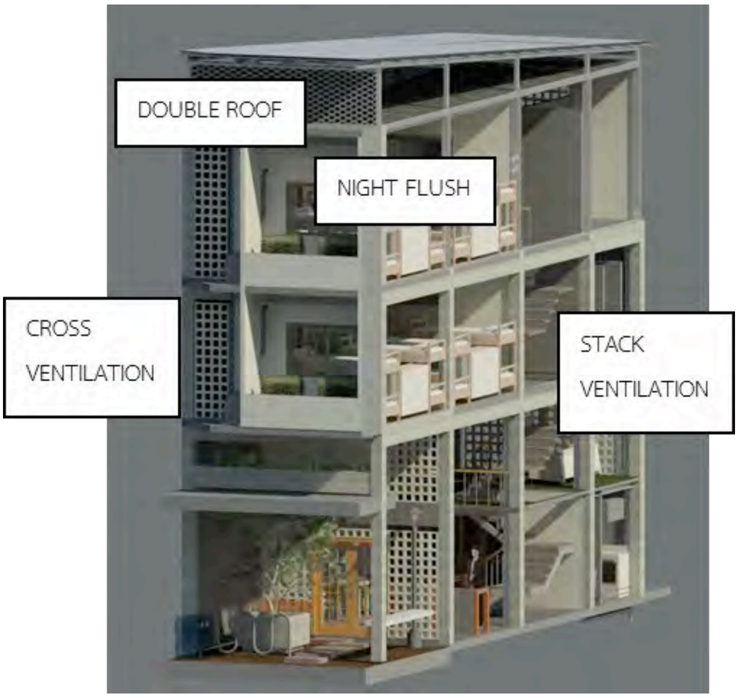

Figure 9. Presentation model

Conclusion

Thermal condition of shophouse hostel can be improved by using passive cooling strategies which are worth an investment. The experiments show an extension of upper comfort limit by up to 5.16°C by providing the openings at the front and the back of the shophouse for cross ventilation and they are not in line with the staircase which promotes stack ventilation. This can solve problems about collecting heat and humidity in common areas such as corridor nearby shared bathroom, community zone, and space under the roof, etc. Night flushing along with double roof also further improve average hourly indoor air temperature by 1.2 – 2.4°C in closed area especially the top floor guest room. Therefore, shophouse SME hotels can improve thermal condition without air conditioning while saving energy and serving the preference and behaviour of guests who normally go out during the daytime.

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Environmental Conditions for Improved Productivity: A Case for Adapting Post-war Constructed Office Buildings in UK

Thajnu Rashid[1], Mariam Kapsali[2]

[1] Architectural Association School of Architecture, London, United Kingdom
[2] Architectural Association School of Architecture, London, United Kingdom

Abstract: Post-war constructed office buildings exist within a pre-defined set of physical, aesthetic and environmental constraints. This research proves that revitalising existing structures by tackling their constraints through responsive interventions can be a catalyst for change in an attempt to counter carbon emissions and adapt these buildings to a warming climate. Research was undertaken by doing a comparative field work between two post-war constructed office buildings that are very contrasting in nature, Elizabeth II court, Hampshire has gone through extensive refurbishment using environmental design strategies and Lee Gate House, Lewisham has seen only minimal changes over the years. Findings from field studies were further validated through analytic studies in order to crystallise an environmental design framework that can be used as a refurbishment approach for upgrading these buildings.

Keywords: Urban Regeneration, Office Buildings, Productivity, Refurbishment

Introduction

Energy used by non-domestic buildings approximately contributes 18% of UK's carbon emissions. By 2050 it is estimated that floor area used by non-domestic buildings will increase by 35% and 60% of this will be made by existing building stock (DCLG, 2005b). According to the valuation agency of the UK government, post-war constructed office buildings constitute 40% of the non-domestic building stock in UK today. There will be a huge environmental cost to pay, if a 'demolish and rebuild' path is chosen to replenish the entire non-domestic building stock. This leads to a compelling argument for extending the life of post-war constructed office buildings by refurbishing them.

Current state of post-war constructed office buildings varies widely with some being listed for demolition or left unused, while others are being converted to apartments or continuing to function as offices. Latter has poor internal environmental conditions compared to modern offices. Commonly seen issues in buildings functioning as offices are poor daylight, overheating and substandard indoor air quality (Burton et al, 2000). These issues create poor working conditions for occupants which in turn has a detrimental effect on their productivity (Nicol et al, 2007). This research focuses on refurbishment strategies that could be used to improve internal environmental conditions, consequently enhancing productivity of office users and extending the life of the building.

Building Characteristics

The most common office building typologies constructed during 1960’s are deep plan type and the spinal/rectilinear type (Burton et al, 2000). This research focuses on adaptation strategies for the rectilinear typology, as it provides more flexibility in modifying the building envelope.

Figure1. Deep plan and rectilinear typology of 1960’s Office building construction (Source: Burton et al, 2000)

Rectilinear typology has linear floor plates which were originally designed for cellular workspaces connected by a central corridor. These are heavyweight buildings with two vertical cores. The envelope plays an important role in the overall energy consumption and indoor environment.

These buildings include cavity walls with U-values between 1.3 to 1.7 W/m2K (Baker, 2009). The construction method constitutes of in situ concrete super structure and the fabric is made of pre cast concrete frames with infill panels.

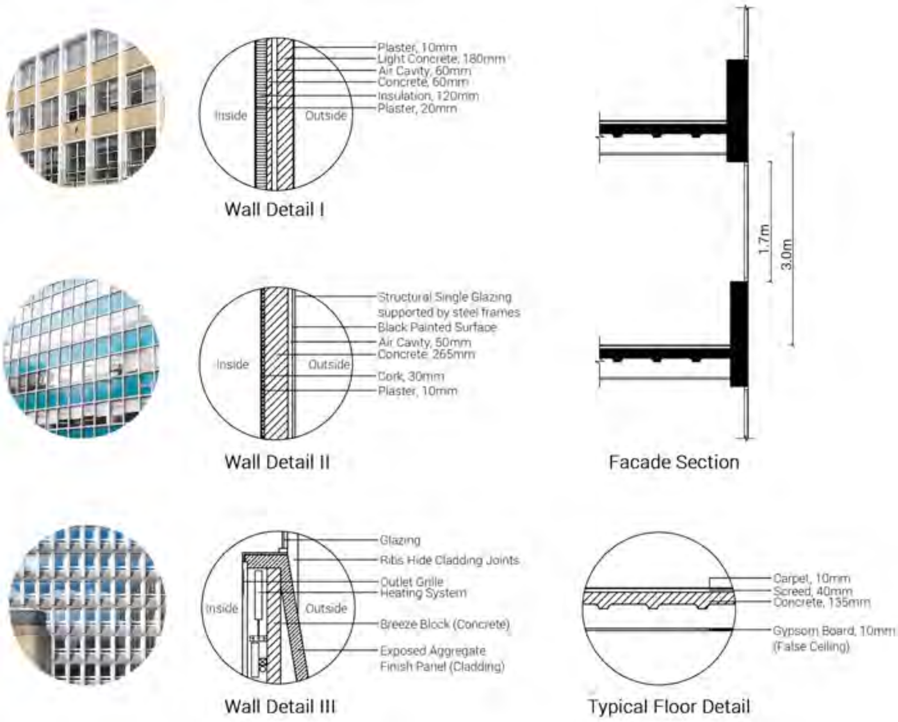

Figure2. Typical wall construction details of office buildings built from 1950’s
(Source: Baker, 2009; Botti, 2012)

Office Buildings under this typology are typically exposed to the outdoor environment with minimal obstructions from surrounding buildings. Environmental conditions may vary depending on the location of building, offering a multitude of design possibilities for retrofit. The top storeys of these buildings are exposed to higher solar gains with minimal or no obstructions, while the lower floors are usually used for retail.

Productivity

A holistic approach to office design or refurbishment should consider the environmental parameters that can be influenced by a designer to make the work space more productive. There is clear evidence from existing research that thermal environment has significant impact on the productivity of office users (Roelofsen, 2002; Nicol et al, 2004). A single temperature value for peak productivity is not justifiable in a free running environment since it does not consider physical and behavioural adaptation of the occupants. Majority of studies on actual office buildings, relating productivity to thermal environment indicates stable productivity conditions can be achieved within the range of 21^{0}C to 25^{0}C and that productivity may drop up to 2% if temperature go above or below this range(Roelofsen, 2002; Sepanen et al, 2006; Nicol et al, 2004; Lan et al, 2010). This research aims to explore design parameters that will have an influence on productivity by improving internal thermal conditions.

Fieldwork

Field studies were conducted in two post war constructed office buildings representative of the rectilinear typology aiming to evaluate the impact of indoor work environment on user's perceived productivity.

Leegate House, Lewisham, London

Typical of the 1960's concrete frame structure, the building envelope is made of pre-cast concrete with thermal plasterboard insulation and facial brick cladding. The building was refurbished in late 1990's, with minor interior and service repairs. Energy bills of 2015 indicate high energy consumption with an annual load of 250 KWh/m^2.

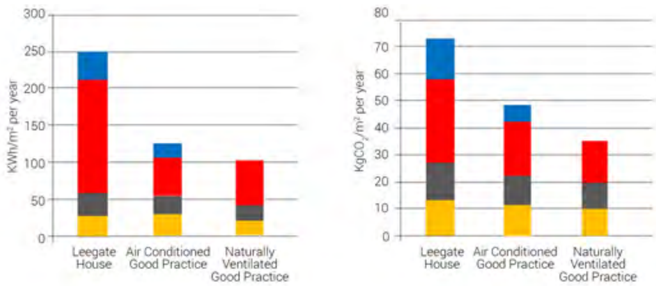

Figure 3. Comparison of annual energy consumption and Carbon emissions with good practice standards, CIBSE guide F.

Figure 4. Aerial view of Leegate House. Sun path (Source- www.gaisma.com) (left) and main elevation of Leegate House facing west (right).

The second and fifth floors of the building were chosen to be studied since the floor layouts are adapted to different working patterns and businesses. The measurements were taken on 13th to 20th of May.

Internal temperature within the workspace follows the fluctuations of outdoor temperature very closely due to the impact of lightweight interiors (Figure 5). Poor envelope performance and uncontrolled infiltration through fenestration has lead to high heat loss during night time, which indicates high heating loads during winter.

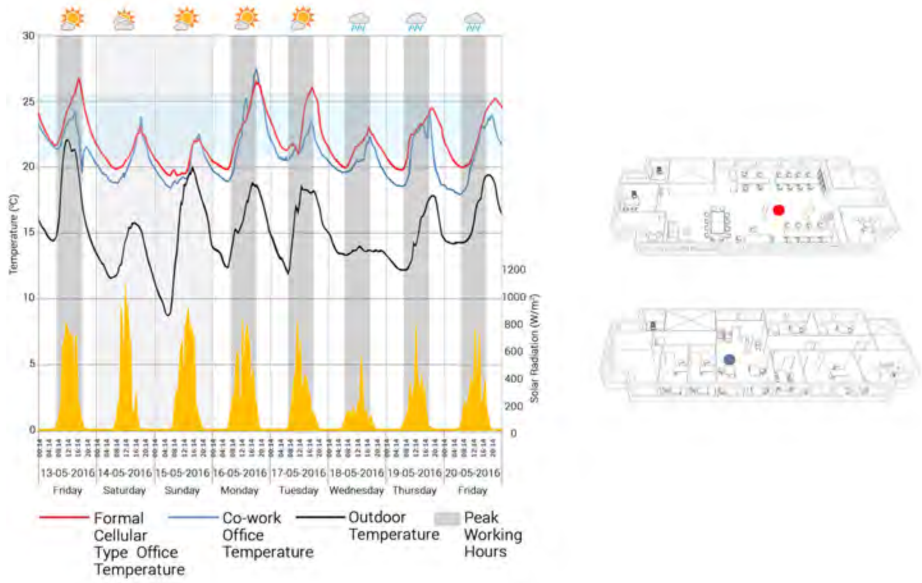

Figure 5. The graph on left shows comparison of data logger readings from Co- work and Formal Cellular type offices in Leegate House. Key Plan shows position of data loggers in both floors.

There is frequent over-heating within the formal office which is free running during summer. Temperature peaks are observed in offices on working days with high occupant density. Current occupant density is low when compared to British Council for Offices density standards. With higher occupant density, the overheating risk is higher. 90% of the occupants reported poor productivity levels due to uncomfortable thermal conditions within the building.

Tenants frequently experienced glare and had to rely on roller blinds to counter this problem and direct solar gains during working hours. This quite often led to a ‘blinds down lights on effect’ with low daylight levels. This field study clearly shows that interventions of this type did not help improve indoor environmental conditions. The design possibilities offered by the structure are often left unexplored and lead to uncomfortable working conditions that may crucially affect the health and wellbeing of the occupants.

Elizabeth II Court, Winchester

Elizabeth II Court was chosen for second field study as it is a good example of refurbishment that made indoor environmental conditions on par with new build offices. The building consumed 260kWh/m^2 of energy before refurbishment with annual carbon emissions of up to 72 kgCO_2/m^2 primarily due to leaky pre-cast concrete facades (Figure 6). The building was stripped back to its concrete frame, new services and innovative natural ventilation systems were integrated within the constraints of an urban context.

Fieldwork was carried out on third and fourth floors of this building, since third floor retains original concrete frame and fourth is an extension to the existing structure. Spot measurements were taken, measuring air temperature, air velocities, surface temperature and lux levels at different floors. Data loggers were placed on these floors from 2nd July to 9th July in order to track temperature and humidity variations throughout day and night.

Users of these two floors were surveyed through a set of questionnaires on occupant comfort and satisfaction of the work environment.

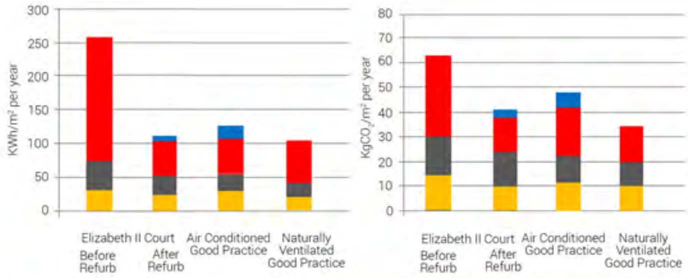

Figure 6. Comparison of annual energy consumption and Carbon emissions with good practice standards, CIBSE guide F

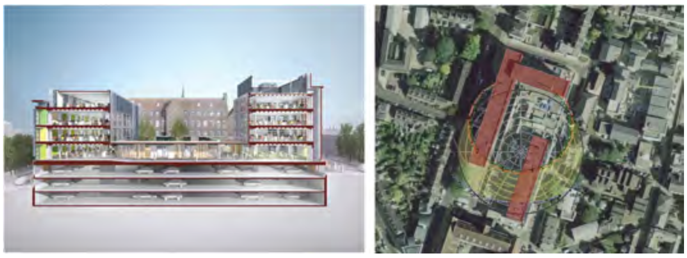

Figure 7. Sectional elevation of the building facing South (left). Lower three floors are used as car park and workspaces are located on the upper floors. The complex is bound by busy roads on the North, East and West sides (Fisher, 2008). Aerial view of Elizabeth II Court in Winchester (right) Sun path (Source- www.gaisma.com)

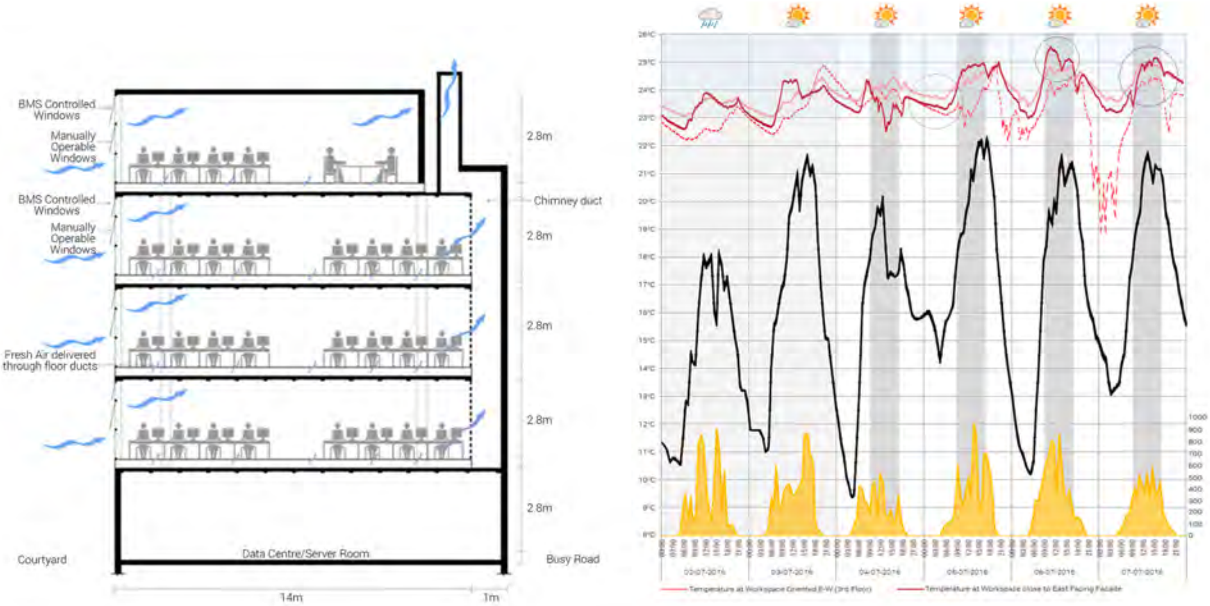

Figure 8. Image on left shows wind driven ventilation system, driven by air movement facilitated through automatically controlled windows facing internal courtyard to pass through a series of chimneys along the facades facing the streets. Graph shows temperature variation within block facing East-West (right). Data loggers were placed on three locations- close to the facade, centre of the workspace and inside the chimney.

On site spot measurements showed that average indoor temperature was around 3.5°K above the outdoor temperature. The effect of night ventilation and thermal mass of the existing structure can be seen on 7th of July where stable indoor thermal conditions are maintained through opening of the chimney shafts (Figure 8).

The temperature fluctuations within fourth floor extension had shown unstable thermal conditions. Users of this floor perceived low productivity levels when compared to third floor. Survey results revealed that occupants are concerned by the operation of automated windows, controlled by building management system. The set point temperature when windows open is set to 15^{0}C during mild and summer season. Users expressed discomfort especially during mild climate as temperature often dropped below comfort. Fine-tuning the settings with slightly higher set points during mild season can help to resolve this problem.

Overall occupant survey results showed highly satisfactory working conditions. And occupants were sensitive in the ability to have an influence on their immediate surroundings. The most valued aspects included ventilation control, window operability, shading control and daylight quality of the workspace. Although users expressed discomfort at temperature above 25^{0}C, they were able to maintain comfort with the help of desk fans. This highlights that in a free running building, provision of adaptive opportunities to users helps to maintain productivity at higher temperatures (Baker, 2009).

Refurbishment Strategies

Simulation Studies

Office spaces in post-war constructed buildings are either owner occupied or leased out to the tenants. Strategies for improving the indoor environment range from possibilities of minimal to deep refurbishment practices. Three levels of refurbishment strategies are tested based on the potential of passive environmental strategies.

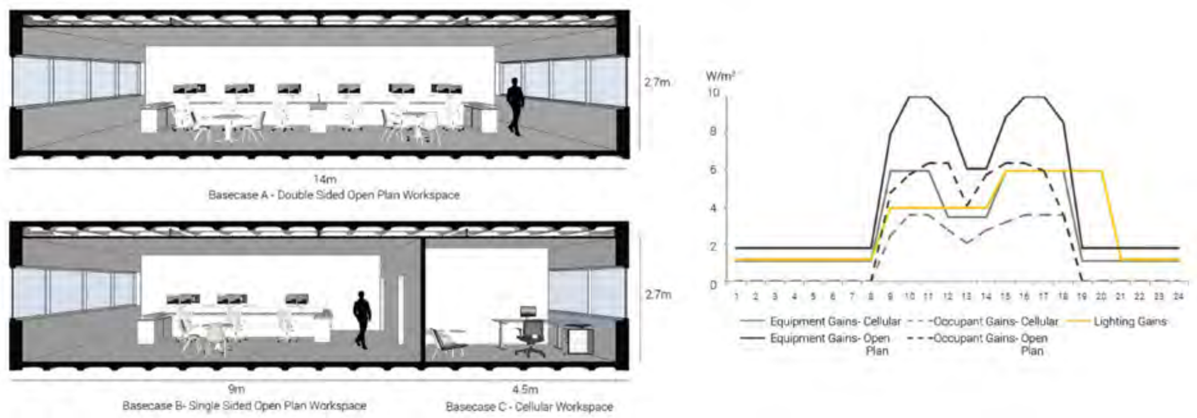

Figure 9. Image on left shows framework for base case, derived from structural characteristics of 1960's office building typology. Graph on right shows internal gains considered for the analytic study.

Aim of analytic study is to identify different intervention options and to estimate how these would result in improving comfort and productivity of the occupants. Improvement in productivity is measured using the criteria defined under the productivity section of this paper. The potential of the existing facade typology and structural characteristics of the buildings were analysed to develop simple and practical solutions for refurbishment. Open studio and Energy plus software were used for thermal simulations and DIVA plug-in for Rhinoceros 5 software was used for daylight simulations.

- × Strategy 1 implementation includes only internal changes without altering facade elements or services.
- × Strategy 2 implementation includes Scenario 1 changes plus facade re-cladding.
- × Strategy 3 implementation includes replacement of the facade and services

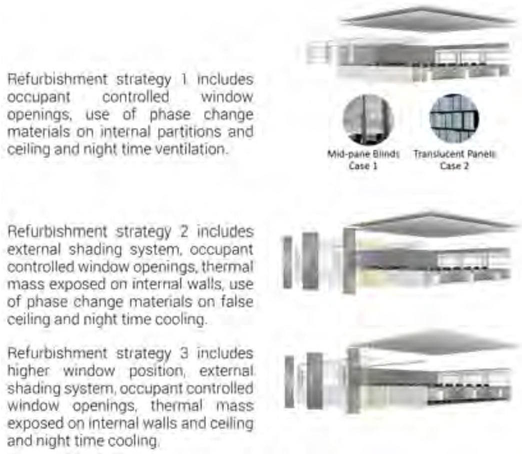

Figure 10. Illustration of three refurbishment strategies

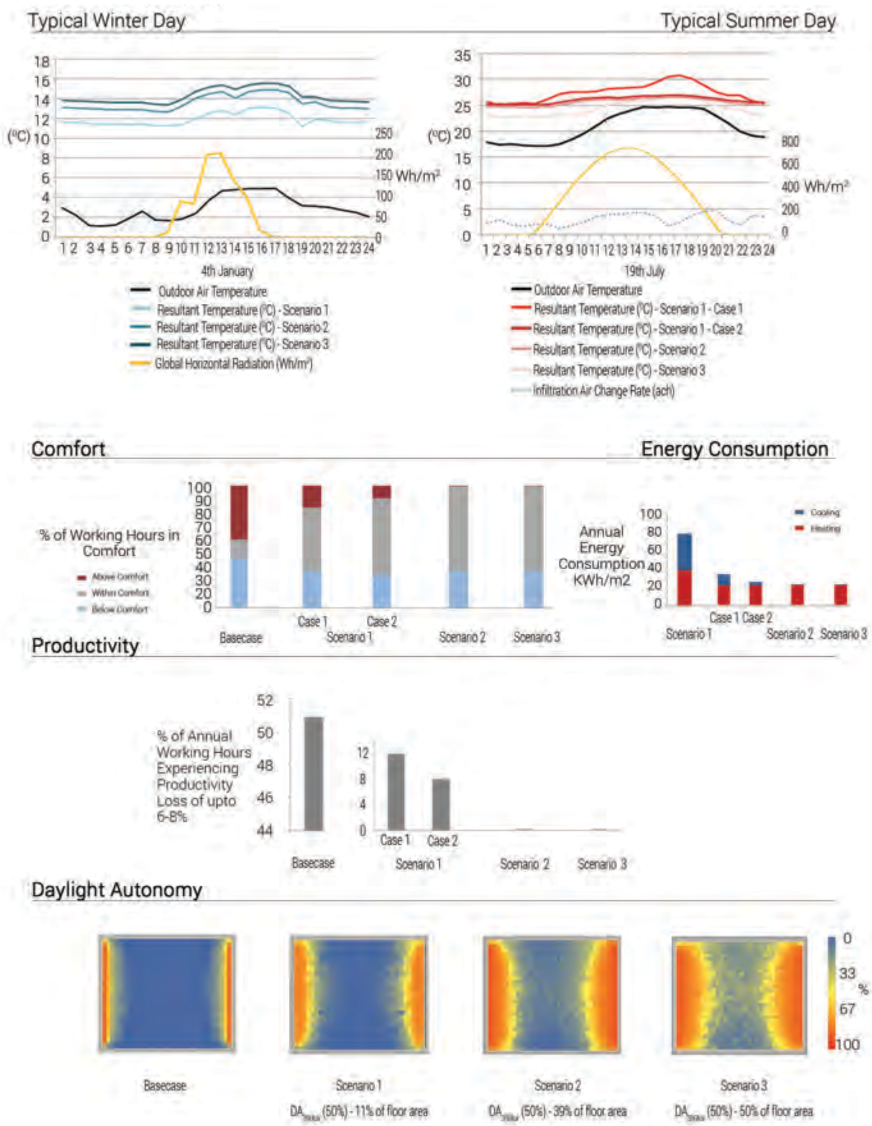

Figure 11. Simulation results for refurbishment strategies 1,2 and 3 (Source: Open Studio, Energy Plus, DIVA)

Outcome from analytic studies implies that 5-6K temperature difference can be achieved by application of night cooling with exposure of thermal mass. Further, use of overhangs increases the number of occupied hours within comfort by 24% when compared to the base case with no shading device. Significant improvements in visual and thermal performance can be achieved through refurbishment strategies 2 and 3. Productivity loss is completely minimised in both cases due to improved thermal comfort.

Strategy 3 improves daylight quality of the work-space remarkably by achieving mean daylight autonomy of 50%. Simultaneously the adaptive nature of external shading devices minimises glare problems.

Adaptability of facade elements to external environmental conditions is an efficient method to achieve a range of comfortable conditions within the workspace whilst simultaneously providing occupants an option to control their immediate surroundings.

Conclusion

This research aimed to extend the life of post war constructed office buildings and improve occupant productivity through the application of environmental design strategies. In this built typology, envelope plays an important role in overall energy consumption and in regulating indoor environmental conditions. Integration of passive solar and daylight strategies was proven effective to counter thermal and visual discomfort. Further application of passive cooling measures significantly minimised overheating and energy consumption achieving free running conditions during mild and summer period.

Thus revitalizing the existing structure by tackling the constraints through responsive interventions can be a catalyst for change to counter carbon emissions and adaptation of these buildings to global warming.

The proposed design framework influences productivity through a responsive physical work environment. After provision of a shell which offers physical comfort, psychological and functional factors are the other aspects which influences occupant productivity in workspace. Further research needs to be done in this area to understand the role a designer can play in influencing these factors.

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Microclimatic conditions of internal courtyards in warm climates and their influence in eco-efficient construction

Juan Rojas-Fernández[1], Carmen Galán-Marín[2] and Enrique Fernández-Nieto[3]

[1] Department of Building Construction. E.T.S. Arquitectura, University of Seville, Spain.
Email: jmrojas@us.es
[2] Department of Building Construction. E.T.S. Arquitectura, University of Seville, Spain.
Email: cgalan@us.es
[3] Department of Applied Mathematics. E.T.S. Arquitectura, University of Seville, Spain.
Email: edofer@us.es

Abstract: A reduced shape factor of the building has become a general recommendation in order to achieve eco-efficient architecture in any climate in spite of the fact that it was made to be applied to cold climates. As a result, this pattern of compact shapes is widespread all over the world. However, it is based on a simplified model of the interaction of architecture with its environment in which the air surrounding the building is considered to be at the same temperature. Nevertheless, this paper will show that in climates such as the Mediterranean, the existence of microclimates induced by the building itself, for instance inside internal courtyards, indicate a more dynamic interaction. In spite of a higher shape factor, more complex shapes can be explored that take advantage of these microclimates to achieve more eco-efficient buildings.

Keywords: microclimates, shape factor, Mediterranean climates, courtyard, eco-efficiency.

Introduction

The most efficient strategies for increasing eco-efficiency in buildings are those adopted in the early stages of design (Olgyay & Olgyay 1963). The shape of the building, the most prominent aspect of the architect's responsibility, is one of these. It would therefore be useful to provide clear and simple criteria to be used by architects to orientate them from the first sketches. Unfortunately, it is not this simple as we will show in this document.

One of these criteria is the shape factor that relates the envelope of the building and its interior volume (F_f=S/V). Widespread recommendations on energy-efficient building design, such as, “Passivhaus primer: Designer’s Guide” (International Passive House Association 2014) advise reducing the envelope transmittance as well as reducing the surface to volume ratio of the building. That is to say, they suggest compact designs that reduce the shape factor. The objective is to limit the energy flow, preserving the largest quantity of energy possible in the interior. It is true that the recommendations, such as Passivhaus, permit greater shape factors but in exchange for an uneconomical increase of insulation.

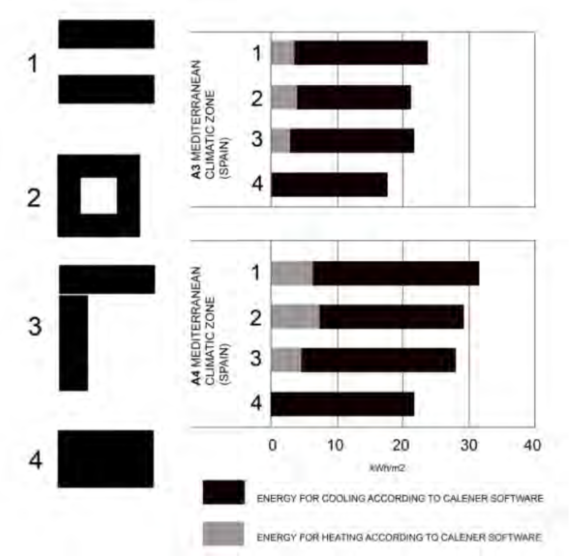
In spite of the fact that it was created for cold climates, this simple paradigm has been imposed by different administrations in many countries with warm climates (Spain being among them), by means of laws, criteria for public tenders or mandatory energy ratings.

This has led to the increasingly widespread appearance of buildings with very simplified shapes. Designing buildings with the shape of very compact boxes, cylinders or spheres is considered a good solution to guarantee better energy efficiency. This condition in current architectural design in both warm and cold climates may result in architecture with more complex shapes and spaces like internal courtyards becoming less common. Several authors express doubts about the validity of this shape factor for warm climates (Depecker et al. 2001) and even for colder climates (McLeod et al. 2013; Sameni et al. 2015).

Hypothesis for homogeneous outside temperature

The recommendations that limit the shape factor are based on physical principles taken into account in energy simulation programs. The energy exchange with the outside is transmitted through the building surface, the envelope. Therefore, limiting this exchange, by decreasing the surface of a given volume, can help to maintain the difference in temperature between the inside and outside with less energy consumption.

Energy simulation programs, such as EnergyPlus TM, that assume these principles have served as the basis for numerous scientific papers (Gratia & De Herde 2003). This scientific information was used in turn to justify the recommendations and energy regulations which favour the restriction of shape factor. Official programs for the mandatory evaluation of energy performance certificate for buildings, such as Lider-Calener in Spain, use the same approach, favouring more compact designs for buildings (Díaz Guirado & Allepuz Pedreño 2016), that is to say, with a lower shape factor in the warmer regions of Spain (Fig. 1a).



a

	Outdoor conditions simulations	Simulations using CFD	Free of charge software	Open sauce	AutoCad BIM / Sketchup import
Lider-Calener			■		■
ANSYS Fluent	■	■			■
DesingBuilder	■	■			■
Ecotect Analysis	■				■
SUNtool	■		■		■
Solene	■		■		
RayMan	■		■		
URSUS	■		■		
GreenCanyon	■	■	■		
EnergyPlus		■	■	■	■
ENVI-met	■	■	■		
Software using FreeFem++	■	■	■	■	

b

Figure 1: a) Energy for cooling and heating different building shape with same volume according to Lider-Calener (official Spanish software). b) Comparative analysis of different energy calculation software.

At this point, an important issue arises: the bases for calculation of these programs accept the hypothesis that there exists only one external reference temperature for the Outside Surface Heat Balance in any weather. In cases such as EnergyPlus, they allow a reduction in the outside temperature when increasing the height of the centroid of the thermal zone/surface, at a rate of about 1ºC per 150m of height (The Ernest Orlando Lawrence Berkeley National Laboratory 2015). Therefore, these simulations assume the existence of a homogeneous exterior space that allows the adoption of a simplified exterior-interior heat transfer model.

Different energy calculation software has been analysed (Fig. 1b). Despite the fact that some of them, such as EMVI-met or Green Canyon, allow an approximation of different aspects of microclimatic behaviour in courtyards, only original numerical simulations with FreeFem++ have been able to calculate a precise difference in air temperature from that of the air temperature outside (Rojas-Fernández et al. 2012).

Experimental

To verify precisely if there is a single homogeneous exterior temperature, as most programs assume, a monitoring campaign has been developed, analysing real existing buildings in Andalusia (Spain). The outdoor spaces selected are very characteristic of the architecture in the area: courtyards (Fig. 2). The buildings are located in Córdoba and Málaga, constituting a good representation of different variants of the Mediterranean climate in Spain. Courtyards of different sizes and types have been chosen. Wind speed and direction, surface temperature of walls, boundary layer temperature, humidity and temperature, simultaneously in different parts of these spaces and on the roof of the buildings, have been recorded. The data loggers are specific for measuring outdoor temperatures and have been protected from the direct incidence of solar radiation.

a

b

Figure 2a,2b: Courtyard studied in the present research: a) 17th Century building, Córdoba, Spain. b) Contemporary hotel in Málaga, Spain (Hombre de Piedra Architects).

Measurement campaigns were conducted between June and October, repeated over three consecutive years and a week was recorded for each courtyard.

Results

The distribution of the temperature drop from the outside in the courtyards of Cordoba and Malaga are shown in the following figures.

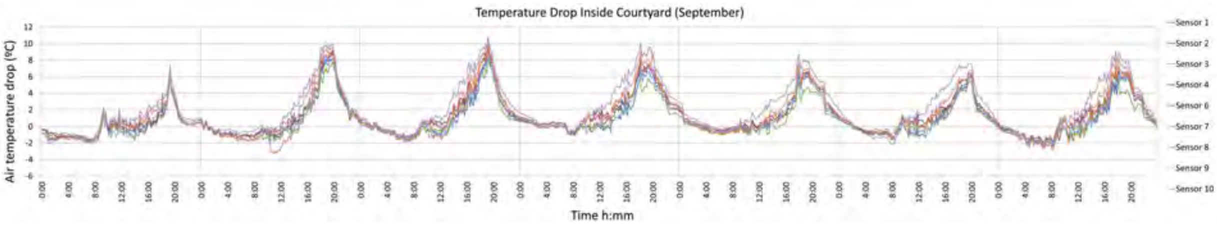


Figure 3: Temperature drop in the Córdoba courtyard from outside temperature.

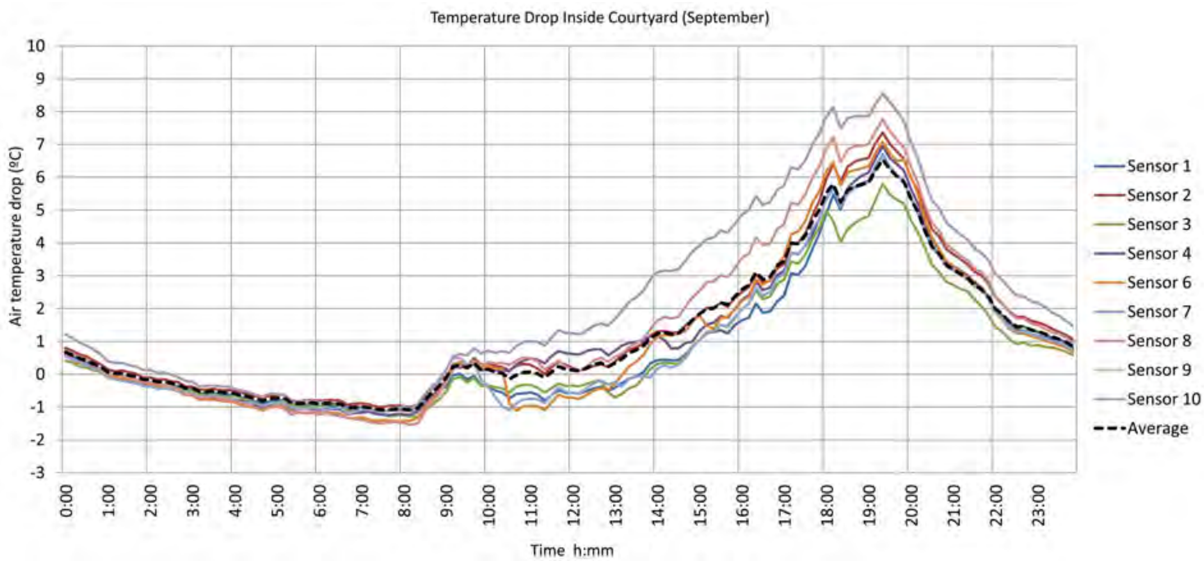


Figure 4: Average temperature drop in the Córdoba courtyard from outside temperature

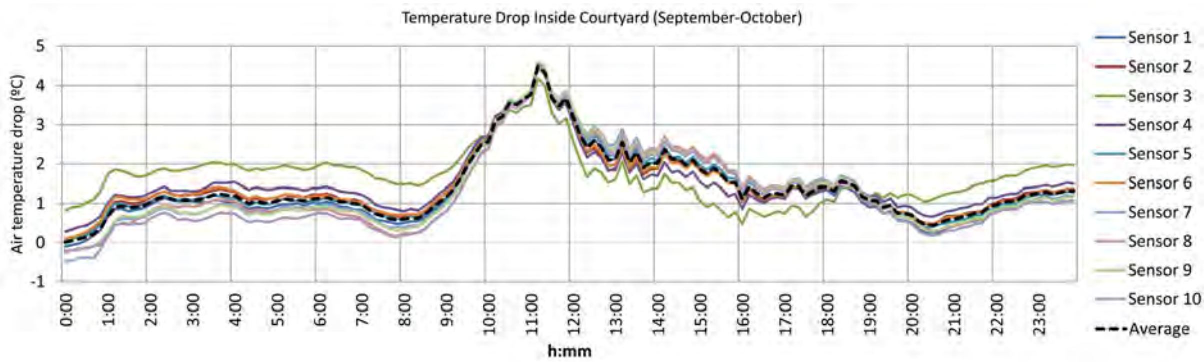


Figure 5: Average temperature drop in the Málaga courtyard from outside temperature.

Figures 4 and 5 show the average air temperature differences at every hour of the day between the inside and the outside of the courtyard over a week. The behaviour of the courtyards is more remarkable if we observe only the evolution of the temperatures in the ground floor. This floor is the most interesting because it is normally where Mediterranean buildings are most open to the courtyard and as such is where the majority of air is taken in. It is also the level where this space is used and inhabited. Figure 6 shows, in the case of the courtyard in Cordoba, air temperatures outside and inside the courtyard for a given summer week (June). During the day, lower temperatures were recorded inside the courtyard than outside.

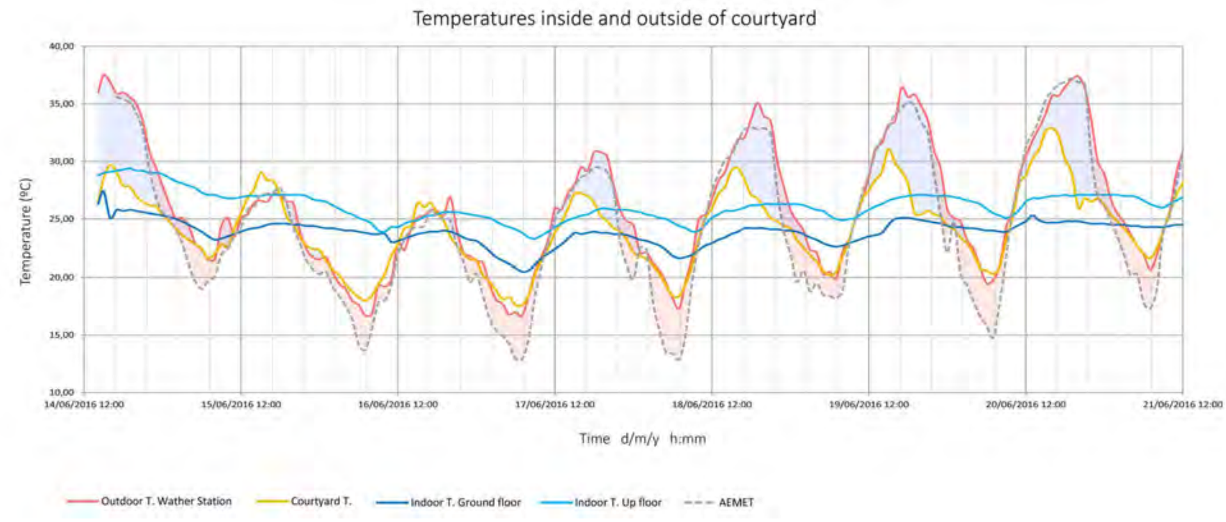


Figure 6: Registered temperatures inside and outside the ground floor of courtyard, Córdoba, Spain.

The external thermal sensor shown in figure 6 (red line) is on the roof of the building as a part of the weather station. In spite of the fact that this sensor is specially shaded and ventilated, we had to be sure that it wasn't recording the effect of the high radiations that is typical in this climate, in addition to air temperature. For this reason, the record of our sensor was compared to the air temperature record on this day in Córdoba by the Official Spanish Agency of Meteorology (AEMET. Gobierno de España 2016). On one hand, this is the most reliable source of meteorological data. On the other hand, we must take into account that this official weather station is not located in the centre of Cordoba, where the studied building is, but at the airport, situated 6.94 km away in the outskirts of the city. It can be observed that the maximum temperatures recorded by our sensor are very similar to the temperatures recorded by the official AEMET weather station at the airport. This clears any doubts about overheating in our weather station. However, the minimum temperatures recorded by our sensor are higher than those recorded at the airport. This is as a result of the well-known Urban Heat Island Effect.

The experimentation campaign shows the dynamic thermal relation between the walls of the courtyard and the air confined between them. Comparative measurements have been made between the surface temperature of the building walls and the air in contact with them in the courtyard space. Therefore, two sets of thermocouple probes have been placed, some in contact with the wall to measure the surface temperature and others in the space in front of it 10mm away to measure the air temperature in the layer of air in contact with the wall (boundary layer). These measurements will allow us to check the direction of heat flow between the inside and outside of the building. The results obtained are shown below.

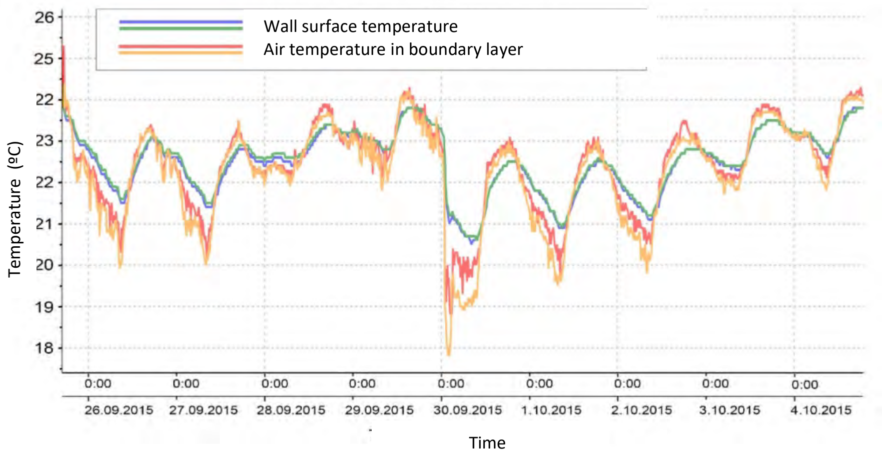


Figure 7: Wall Surface temperature and air temperature in the air layer in contact with the wall (boundary layer temperature) in the courtyard of Málaga, Spain.

At this time of the year, the outside air temperature at night is always lower than the surface temperature of the wall (sometimes up to 3ºC lower as shown in the peak for figure 7). Therefore, in these Mediterranean climates, the considerable difference in night temperature allows the building to lose heat to the outside by conduction, convection and radiation through its envelope.

Discussion

It can be observed that courtyards, mainly in Mediterranean climates, generate a microclimate, in which the temperatures differ from that of other external areas around the building. The maximum average difference for the building in Córdoba, with this climate and this time of year, was found at 19:00 solar time and reached more than 8°C (Fig. 4). This is consistent with the differences recorded by other research (Alvarez 2001). It is remarkable that it is around this same time that the outside temperatures reach their maximum. For this reason, the positive effect of a courtyard's microclimate on the building is more significant. There is also a drop in temperature in the courtyard in Malaga (Fig. 5) although it is somewhat lower because the outside temperatures were lower than in Córdoba (Fig. 4). Due to the milder climate in Malaga and the different architecture of the patio, the maximum difference of 4.5 °C occurs in the morning. The parallel evolution of temperatures at different heights in the Córdoba courtyard (Fig. 4) shows the existence of a stratification phenomenon. Figure 6 shows a very clear thermal pattern inside the courtyard with remarkably lower temperatures than outside during the day. These differences are going to disappear at nightfall. In fact, the graph shows that sometimes the courtyard temperatures can be a few degrees higher than outside during the night and early morning. It is also necessary to highlight the stable evolution of the interior temperature in the ground floor of the building and first floor (dark blue and light blue respectively) that are within the range of comfort in this naturally ventilated building. The effect of the courtyard can contribute considerably to the positive behaviour of the interior temperatures. The differences between day and night temperatures are remarkable. In the airport, this difference reached 23.1ºC and a few degrees lower around the studied building where it reached 17.3ºC. This means that in this warm climate there are opportunities to propose designs that favour heat transfer during the night by conduction, convection and radiation. For instance, one possibility could be to design a low, compact form to allow wider and closer contact between buildings and the outside environment. Figure 7 shows, in the courtyard, this heat flow between the inside and outside of the building.

The data shows that the actual behaviour of the air in these climates is complex due to its interaction with the architecture. Thus, it is not correct to consider that all the surroundings of a certain building in any climate are exposed to the same conditions and outside temperature. The exterior temperature around the building is not homogeneous due to existing microclimates like those in courtyards. There are other phenomena around buildings that also generate well-known microclimates in warm regions such as urban canyons (the narrow streets of Mediterranean cities) and microclimates generated by vegetation (evapotranspiration phenomenon), amongst others. The results obtained lead to reconsidering the preciseness of conventional energy simulation models. By not contemplating the existence of these microclimates, most widespread conventional energy simulations are not able to balance the importance and potential of these spaces. Moreover, in these simulations, the introduction of spaces such as courtyard results in a poorer energy performance of the building by increasing the facade surface without taking into account any of their advantages. Nevertheless, designs with low shape factor and over-insulation are at risk of overheating, both in Mediterranean climates and even in colder climates.

Conclusion

In light of the experimental results, it is possible to conclude that designing courtyards in Mediterranean buildings has the following advantages:

- To allow the creation of outdoor spaces with microclimates that moderate temperature. These microclimates have been traditionally used in a passive way to improve the performance of these buildings. However, it is also possible to use this technique in contemporary designs, introducing this fresher air in the air conditioning system and improving the energy performance of the building. To evaluate this, a better quantitative knowledge of these phenomena is required.

- To provide a bigger surface for heat transfer to the surrounding environment during the night. This is done both by conduction through the air in contact with the walls and by radiation, releasing heat into the typically cloudless night sky of these climates. In contrast to this, exposing more facade surfaces could assume a greater heat gain during the day, especially under the incidence of solar radiation. However, covered shapes can be designed to enable many of these walls to be sufficiently shaded during the day.

-To improve ventilation conditions, avoiding overheating. Complex shapes and courtyards allow smaller widths of the interior spaces of buildings, facades at different orientations with different wind pressure and temperature conditions, and all of these favour the possibilities of cross-ventilation.

- Last but not least, in Mediterranean climates, the architecture of more complex shapes and courtyards is usually more interesting and provides a more satisfactory human experience by keeping contact with nature. This improves the adaptive thermal comfort (Nicol et al. 2012) and saves energy by keeping the air conditioning off for longer.

The development of precise energy tools to be used during a buildings inception is a priority for achieving energy efficiency. The present study highlights the fact that, as long as more sophisticated tools are not integrated in building design, general recommendations such as a reduced shape factor do not have validity in warm climates, due to the complex interaction of shape and climate. These over-simplified techniques can even be harmful when attempting to achieve higher eco-efficiency in construction: they increase the risk of overheating and create a strong paradigm that complicates the exploration of new innovative strategies based on more complex shapes, for instance by using internal courtyards and their microclimatic conditions.

Acknowledgments

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Improving the Ambient Air Temperature in Small Outdoor Spaces

Nihal Al Sabbagh

Architectural Association Graduate School, London, UK

Abstract: The hot weather conditions in Dubai have discouraged the use of outdoor urban spaces, leading to huge dependence on mechanical cooling and its use indoors. The purpose of this study is to investigate the cooling effect of selected strategies on the outdoor ambient air temperature using the numerical model ENVI-met. Variables of three strategies were tested initially: orientation, geometry and vegetation, where the coolest parameter of each was incorporated into one scenario, named the enhanced scenario. This scenario was compared later with the existing scenario, representing the site conditions of an educational campus in Dubai, and a worst-case scenario, combining the warmest parameters. Results revealed that the SW-NE orientation, the highest height to width ratio (H/W) ratio of 4 and the groups of trees and continuous grass achieved the highest reduction of air temperature. The EW orientation, 0.5 H/W ratio and no vegetation recorded the highest temperature levels. The comparative results highlight a slight improvement in the enhanced scenario over both the worst-case scenario (of 1.1K) and the existing scenario (of 0.9K). The air temperature patterns and wind movement on this campus helped to understand several outdoor behaviours useful for guiding a sensible design for combating extreme heat conditions in urban spaces.

Keywords: bioclimatic, ENVI-met, landscape, microclimate, thermal comfort, outdoor space

Introduction

Building settings creates urban patterns that control the wind direction and the solar access; hence the thermal comfort levels of outdoor spaces and the energy consumption in indoor ones. Empirical research has recently accumulated seeking to understand the relationship between the built environment and the microclimate in many urban situations. At street level, the space morphology, orientation, materiality, components and vegetation are considered the main factors shaping the thermal environment. Therefore, improving the outdoor thermal environment ought to manage such variables sensibly, where an optimum balance between diurnal gains and nocturnal losses is achieved. The present research investigates the synthesized influence of space geometry, orientation and vegetation on the ambient air temperature. Parameters within each variable that demonstrate a cooling effect have been considered; they are examined through the microclimatic simulation tool ENVI-met (Bruse, 2007). The aim was to provide insightful information on the effectiveness of each factor when applied solely or with others.

Geometry and orientation

The distance between buildings defining an open space, their settings and heights play a major role in the incoming and outgoing heat radiation and the wind speed (Johansson, 2006). The negative effect of improper space geometry tends to increase the solar gain and prevent wind circulation on the site. According to Ali Toudert (2005), narrow urban canyons with a lower height to width (H/W) ratio amplify the cooling effect during peak hours of the day more than wider canyons with a bigger H/W ratio do, mainly due to the increased shade. Their study suggests that shading is an effective means of mitigating heat stress in outdoor spaces. A study conducted by K. S. (1994) in the hot humid environment of Dhaka found that on average the daily maximum temperatures decreased by 4.5K when the H/W ratio increased from 0.3 to 2.8, which was fair for achieving thermal comfort levels. However, denser spaces contribute to higher levels of air pollution, due to the entrapment of air particles and ventilation, which raises the temperature levels. Therefore, a balance between shade and ventilation should always be considered (Krüger et al., 2011). Following a proper urban design ratio seems a promising way of improving thermal comfort levels within urban spaces and the surrounding buildings should be planned with this in mind.

The space orientation has more effect on the distribution of the surface temperatures and net absorbed solar energy than on the absorbed quantities. Ali-Toudert and Mayer (2005) argue that the heat stress of an East-West oriented canyon was higher than that of one with North-South orientation and provided a better thermal environment. For Northeast-Southwest or Northwest-Southeast orientations, these canyons have been shown to attain better comfort levels as the shading increases, but with a slight difference, nonetheless. In some cases, a compromise should be made so that the orientation for summer and winter suits the comfort levels of both periods. The orientation factor appears to be less sensitive to the air temperature variations when compared to the H/W ratio of the space. The consequences of N-S and E-W orientations could be modified by the H/W ratio. Furthermore, orientations with higher solar exposure require deeper spaces (a larger H/W ratio), while orientations with shorter periods of solar exposure can tolerate wider spaces with a smaller H/W ratio. Shashua-Bar and Hoffman (2003) reconcile the geometry orientation and greenery factors, where space orientation variations between N-S and E-W orientations have proved to be only slightly different. N-S orientation provided 83% of the shaded areas while E-W orientation provided less shade, only 74%. A recent study by Krüger et al. (2011) demonstrates the effect of orientation not on the percentage of shaded periods but on wind flow and air quality. Studies validate the relation between the wind flow and air quality, since air movement prevents air stagnation and thus pollution blockage. Pollution has been shown to contribute to lower air quality levels and higher temperature levels. This study recommended orienting urban canyons parallel to the wind direction, which would increase the air inflow in the outdoor spaces.

Vegetation

Greenery is apparently the most effective parameter for improving the microclimate, with numerous benefits. Shashua-Bar and Hoffman (2003) demonstrate that 80% of the cooling effect provided within 11 sites in a Tel-Aviv urban complex was due to the shading effect obtained from trees. During the day, trees reduce the penetration of solar radiation by their shade and by the attenuation of the thermal gains due to their thermal mass. A model was used for testing such effects but it ignored the marked passive cooling effect on their surroundings. The process of air exchange of the long and short wave radiations between the trees and their surroundings as contributing to the cooling effect. The dissipation of the heat load is due to evapo-transpiration and convective heat exchange with the air (Al-Sabbagh, 2011).

The consideration of the layout orientation is revealed to be essential for enhancing the cooling effect. The wind factor tends to spread the cooled air around the layout (Robitu et al., 2006). The cooling effect obtained from a green site is due to the low ability of its soil to absorb heat, whilst the vegetation surfaces are shown to absorb much less heat. Givoni (1991) cites various studies that were carried out on the thermal effect of plants in urban areas. The studies reveal the use of greenery as an energy saving method due to the reduction of cooling loads on the surrounding buildings. The effect of landscaping (consisting of trees and shrubs) on the cooling loads of its surrounding buildings was marked by around 50% savings, in that the loads dropped from 5.56kw to 2.28kw and was even more marked during peak load periods (8.65kw to 3.67kw). Givoni's study concludes that applying vegetation confers several benefits such as pollution reduction, noise attenuation and social cohesion.

Regarding vegetation and the microclimate, (Masmoudi and Mazouz, 2004) have evidence that these two are related. The reduction of air temperature on the ground level was found to be about 5^{o}C for the different plan forms tested (square form and rectangular form). The examination of the results showed that the simple presence of vegetation is more effective than its quantity. The increase in the quantity of vegetable masses had no great significance when compared to the influence of applying trees in highly thermally-stressed locations. The study guided the best orientation of trees to be that of north-east/south-west due to the reduction of the solar energy absorbed by the ground surfaces. Densely vegetated areas, however, find it difficult to dissipate heat during the night due to the large concentration of vegetable masses (Wong et al., 2007). Grass surfaces are considered to be of great cooling effect, but still a proposed design ratio between the numbers of trees and the area of grass ratio should be suggested. It is believed to be effective in the cooling process if distributed with enough intervals. An area of 100 m^2 and recommended that 8 trees can be planted 5m apart to achieve a desirable thermal comfort balance throughout the year (Shashua-Bar and Hoffman, 2000).

Methodology and Microclimatic Simulation

ENVI-met is a three-dimensional microclimatic model that incorporates all the parameters that govern an outdoor environment and attains validated results. Due to the various numbers of variables investigated, a test matrix (Table 1) was created to make the simulation procedures easier. Nineteen simulations were run, investigating three scenarios in both summer (August) and winter (January), besides examining the three main parameters of the bioclimatic principles (the orientation, geometry and vegetation). Each of these parameters included several variables, while there were four orientations (NS, EW, NW-SE, SW-NE), three height-to-width ratios (0.5, 2, 4) and six strategies for vegetation (no trees, a continuous line of trees, groups of trees, areas of grass, continuous grass). One parameter at a time was tested during conditions of extreme thermal stress while all others were fixed according to the existing state of the conditions. Dubai Knowledge Village (DKV) was selected for investigation; it is an international educational campus located in a lively business hub named Internet City. The three main comparative scenarios (existing, enhanced and worst) were tested in both on August and January and between 8am and 10 pm. The temperature values given in the output files were averaged that represented the temperature of the whole site during that specific hour. The enhanced model scenario is considered the concluding model for the present study, which incorporates the most effective parameters of the bioclimatic variables under investigation. The present simulation results are based upon a configuration of SW-NE as the orientation, an 0.5 ratio, continuous grass and trees in groups. Simulations were run on the exact duration of the existing and the worst-case scenario, namely, August and January (representing summer and winter respectively) from 8.00am to 10.00pm.

Table 1: The test matrix used for the simulation analysis. Red cells represent the fixed variables during simulation.

Independent variables	Orientation	H:W ratio	Grass	Trees
Existing scenario	20°NW-SE	0.8	No	Tree every 12m
Independent variables	NS	0.5	Continuous	No
	EW	2	Grass pieces	Continuous linear
	SE-NW	3	No Grass	Tree groups
	NE-SW		No Grass	Tree every 12m
Enhanced scenario	NE-SW	0.5	Continuous	Tree groups
Worst case scenario	EW	3	No	No

Effect of Orientation

The four orientations tested were those of the NS and EW and, with a 45o inclination, the SW-NE and SE-NW. The results reveal the SW-NE to have the lowest average temperature followed by the NS, SE-NW and finally the EW orientation, where the highest average temperature values were recorded. The south-facing walls of an EW orientated space are thought to receive the highest levels of solar radiation. These findings corresponded to many studies (e.g. (Ali-Toudert and Mayer, 2005, Shashua-Bar and Hoffman, 2003, (Masmoudi and Mazouz, 2004). Comparing the two warmest orientations, EW and SE-NW, accounts for such values, for where the south-facing facades in the EW orientation receive the highest levels of solar radiation, followed by those in the SE-NW orientation. Building on this interpretation, the NS-oriented space should have recorded the lowest temperature values, yet the SW-NE was revealed to be the lowest of all. The reason for such a finding is identified as the influence on orientation of the shading within the space. The SW-NE orientation created a balance between the two concepts, recording the lowest average temperature values.

The average difference between the four orientations was small, yet a wide variation was observed in the temperature distribution, indicating the importance of orientation for improving the outdoor temperature. The maps indicate a lower maximum temperature in the SW-NE orientation than those of the EW and SE-NW orientation. However, the SW-NE orientation, which gave the lowest temperatures had the lowest average wind speed values, followed by the EW, NS and SE-NW orientations. The SE-NW orientation runs parallel to the prevailing wind, which blows from the NW; and yet it recorded the second highest temperature values. The wind factor, then, was seen to have no cooling effect on the spaces but it does have a 'spreading effect' depending very much on the orientation (Figure 1). This means that a visual analysis sequel to the temperature distribution should be conducted, to forestall a warming effect. In this case, the wind aspect also contributed to enabling the SW-NE orientation to yield the lowest average temperatures.

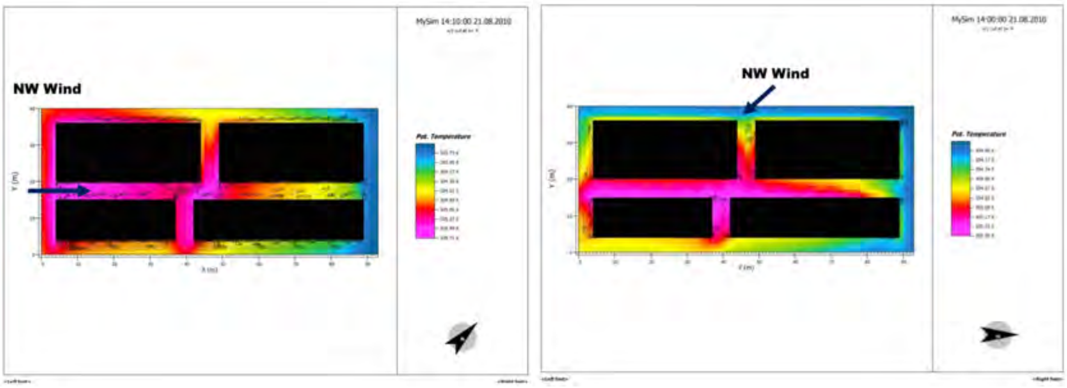

Figure 1: Thermal maps for SE-NW orientation(left) and NS orientation(right) with the spreading effect of wind.

Effect of Geometry

A slight variation was revealed between the three configurations with the highest ratio of 4 that recorded the lowest average temperature values. An inverse relationship between the H/W ratio and the temperature was found. Wide spaces receive more solar penetration and thus more solar gain, while deep ones are sheltered from solar access in proportion to the ratio. The H/W aspect ratio can reduce the maximum temperature levels during the peak thermal stress period when maximum temperatures are recorded, and thus can reduce the average temperature accordingly. As the ratio of the space exceeds 2, the temperature variation is reduced, unlike that of the spaces with ratios below 2, which are considered to strike a balance in the cycle between diurnal heat gain and nocturnal heat loss. The ratio 2 simulations had moderate maximum and average temperature values between the three configurations and yet recorded the lowest minimum temperature (Figure 2). This occurred in the early morning, as a result of the low night flushing and heat entrapped. The 'spreading effect' of wind also seems to be applicable in the geometry simulation results. The 0.5 ratio shows more contours within the space, indicating the turbulence resulting from the wind speed slightly extending the cooled area, but this does not apply to the two other ratios. Moreover, the highest ratio of 4, recording the highest temperature values, revealed the lowest average wind speed values similar to the orientation wind speed and behavior of the temperature. Narrower spaces were shown to provide more shade which in turn reduced the number of surfaces exposed to solar gain and thus enhanced the air temperature more than wide spaces could. The guide is an understanding of the behavior of the temperature and wind in accordance with the reasons for the solar gains.

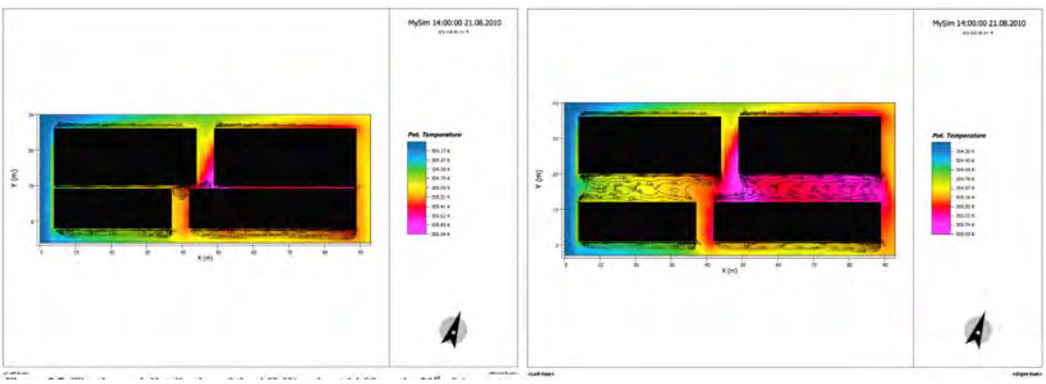

Figure 2: Thermal maps for 4 H:W (left) and 0.5 H:W (right) showing the amount of heat inside the lower ratio.

Effect of Vegetation

As with the two previously investigated variables, the differences obtained between the options for landscape strategies were not high, yet the vegetation proved to be the most effective variable of all. It showed an improvement of 0.6K of the average temperature and 0.7K of the maximum temperature during the peak thermal stress period for the groups of trees and continuous grass option. The maximum temperature difference was greater than the average difference which supports the view that the effect of vegetation increases during the hottest times of day, the reverse of the effect of orientation and in compliance with the geometry in the same periods. The average temperature results comparing the six landscape strategies reveals that the strategy of planting both grass and trees yields the lowest temperature values contributing to a better passive cooling effect. The resulting differences between the no trees scenario and that of continuous grass was 0.3K, which was lower than the difference between the scenario of no trees and that of groups of trees, which was 0.5K. Comparing these carefully makes it clear that the wind is affected by the different strategies. The effect of groups of trees recorded slightly higher average and maximum temperatures than the effect of a central continuous line of trees. Groups of trees, however, interrupted the wind flow vastly more than a central line; they obviously blocked the cooler breeze coming from the north-west from blowing across the space (Figure 3).

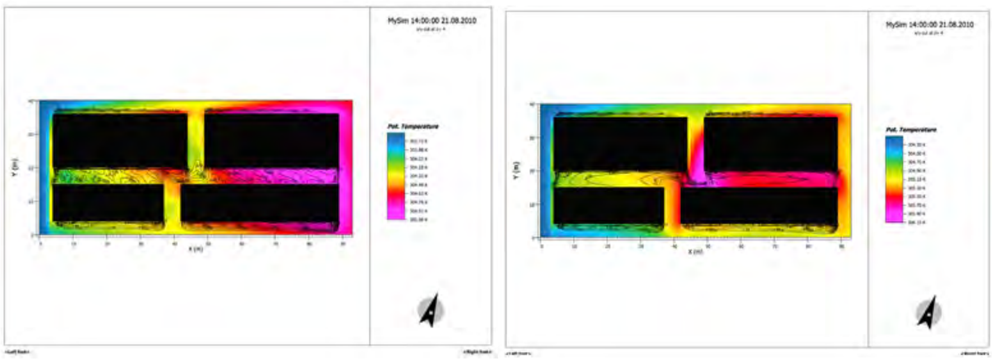

Figure 3: Thermal maps for groups of trees and continuous grass (left) and no trees no grass (right) showing the wind turbulence caused by the trees.

Comparing the three scenarios

The enhanced scenario slightly improved the average outdoor air temperature of the existing conditions by 0.5K in summer and 0.3K in winter, while the enhanced scenario improved the worst-case scenario's outdoor average summer air temperature by 1.1K. The efficiency of the bioclimatic principles applied in the enhanced scenarios was maximized during the peak thermal stress periods. The balance created by the enhanced scenario at these periods of the day in the two seasons was considered vital, yet its efficiency was relatively reduced during winter evenings. The results and findings obtained highlight the presence of a threshold in the size of the bioclimatic parameters applied. The worst scenario recorded the highest temperature values in the summer and lowest in the winter. The enhanced scenario incorporated all the variables revealed to have the greatest cooling effect and thus reduced the air temperature more than either of the two preceding scenarios. It was concluded that the cooling effect of the orientation was 0.7K, the H/W ratio was 0.6K and the vegetation was 1K during the daily peak thermal stress period in summer. The enhanced scenario was based upon the incorporation of the three variables yet the total cooling effect obtained was 1.1K, almost equivalent to that of applying the vegetation effect only. The behavior of the outdoor parameters is quite complex where some variables, such as orientation, are revealed to be less effective during peak thermal stress periods while others, such as geometry and vegetation, proved to be more effective during these periods. This non-uniform pattern is repeated when observing the effect of each bioclimatic principle dependently and in combination.

Wind has more of a spreading effect than a cooling effect. Cool areas should be facing the wind to broaden the cooling effect, while hot points within the space should be sheltered from the wind to prevent this effect. In the case with the enhanced scenario, the breeze comes from the NW and is blocked by the building facing it. The worst scenario recorded much higher values of wind speed, since the model was bare of trees and the space was wide, with a low H/W ratio; hence, it enhanced the wind flow in the space, with almost no turbulence. The existing scenario had a central value between the worst case and the enhanced scenario, where the central line of trees created more wind turbulence.

Conclusion

Vegetation had the most cooling effect of all the three parameters, followed by orientation. Masmoudi and Mazouz (2004) tested the three independent variables investigated here, but in different conditions; their results support the cooling sequence observed in this study. Generally, shading proved to be very efficient in reducing the air temperature during the daily peak thermal stress period, contributing in particular to lower average daily temperatures. Nevertheless, excessive shading is not recommended, since it reduces the heat radiation loss process, ultimately leading to higher temperatures (Hwang, 2010). It was noted that dense vegetation is not preferable and very high H/W space ratios are not recommended.

The coolest orientation that recorded the lowest average temperature values and in turn achieves the longest periods of improvement was revealed to be the SW-NE orientation, followed by the NS, SE-NW and the EW in that order. There are three reasons for this result: the shade provided in the space by each orientation, the temperature of the area facing the prevailing wind, and the position of the southern facades with reference to the angle of the sun in each orientation. The SW-NE orientation reconciled all the above reasons for the lowest values of temperature. The coolest geometry was the one with the highest aspect ratio of 4, where the H/W ratio was shown to be inversely proportional to the temperature. A slight difference was observed between the ratio of 2 and 4 and that between the ratios 0.5 and 2. The reason for this is that narrow spaces find it difficult to radiate their heat to the environment; thus, the inverse relation mentioned has a threshold where the temperature starts to increase again. The coolest vegetation strategy was recorded as the one with both grass and trees, where trees provided shade and evaporative cooling while grass had the advantage of reducing the surface radiation and adding an evaporative effect. Landscape strategies are much too wide to be tested in a single study, although the strategies proposed were based on earlier recommendations. Generally, it was concluded that in extremely hot countries such as Dubai, achieving outdoor air temperatures close enough to the thermal comfort values is impossible in the summer but they can be slightly improved. The application of the proper orientation of SW-NE, a high space ratio of 4, groups of trees and grass considered as the 'bioclimatic application' enhanced the air temperature by a value of 1.1K. This value proved to be acceptable when dealing with the outdoor environment where more significant changes were not possible.

However, the results obtained are promising for passive cooling techniques of the outdoor environment.

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Natural Ventilation Potential in Kuala Lumpur: Assumptions, Realities and Future

Mohd Firrdhaus Mohd Sahabuddin[1], Cristina Gonzalez-Longo[1]

[1] Department of Architecture, University of Strathclyde, Glasgow, United Kingdom

Abstract: Malaysia accounts for 11% of Southeast Asia's carbon emissions in recent years, is the third highest emissions contributor in the region. It has been estimated that 25% of these carbon emissions are generated from the buildings, especially from the electrical and mechanical equipment that are present in residential buildings. Malaysia's capital, Kuala Lumpur, has 81.5% of the high-rise buildings in the country and half of the buildings are residential. They have supposedly been designed as predominantly naturally ventilated, but the occupants had to add inefficient mechanical ventilation to achieve the required cooling. It is due to the lack of acknowledgement of the hot-humid climate of Malaysia by the current building regulations and the fact that the requirements for energy use are not customised for residential buildings. Recent developments concerning the use of green rating tools are helping to improve the sustainable design of buildings. This paper reviews these existing regulations and green rating tools and explores the full potential for natural ventilation in Kuala Lumpur, to substantially reduce carbon emissions while considering both the health and comfort of the occupants. It concludes that the building regulations should be revised to deal with current and future climatic conditions and to achieve the critical conditions that allow for natural ventilation in Kuala Lumpur.

Keywords: Natural ventilation, indoor comfort, indoor air quality, building regulations, Kuala Lumpur

Introduction

The implications of climate change, including heat stress and air pollution, contribute to a wide range of impacts on human's health and comfort in urban areas (IPCC, 2014). More than half of the carbon emissions in the world, that are causing the climate change, will be produced by Asian cities in the next 20 years and it is estimated that 1.2 billion Asians will migrate to the cities over the next 35 years (ADB, 2015).

The carbon emission in the Southeast Asia (SEA) region has increased rapidly from 1990 to 2010 (ADB, 2015). Five countries that are Indonesia, Malaysia, Philippines, Thailand and Vietnam, have collectively contributed 90% of the carbon emissions in the SEA region (Raitzer et al., 2015). Malaysia accounts for the 11% of these emissions in recent years, ranking as the third highest emission contributor in 2014 (ADB, 2015). In order to address this problem, the government of the country has recently signed the Paris Agreement, committing to reduce 45% of carbon emissions by 2030 in accordance to the 2005 baseline (UNFCCC, 2017).

The building sector is one of the largest carbon emissions contributors in the world (IPCC, 2014). In the case of Malaysia, the carbon emissions from this particular sector have been doubled from the 1970s, representing now the 25% of the total country's emissions (Lucon et al., 2014). The residential buildings, construction of which has been quintupled during the last four decades (Lucon et al., 2014), and in particular their mechanical and electrical cooling equipment are the greatest contributors to the emissions. Thereafter, the appropriate ventilation design in these residential buildings, in particular high-risers, is a key element to find solutions to reduce carbon emissions and to overcome the damaging effects of climate change in the future. For example, the buildings in the urban areas such as Malaysia's capital, Kuala Lumpur. There are many challenges concerning the provision of natural ventilation in dense urban areas such as Kuala Lumpur, including the problems associated with the urban heat island effect and air pollution. The current practices in building design have failed to achieve the required environmental conditions for health and comfort and the occupants had to afterwards increase the amount of mechanical ventilation to achieve cooling.

The current building regulations in Malaysia (UBBL) were implemented in 1984 and these are based on the recommendations provided by the United Kingdom's Building Research Station (BRS), which is currently known as Building Research Establishment (BRE); these recommendations were previously applied in Kuala Lumpur and Singapore, both British colonies until 1957 (Said, 2011). The UBBL 1984 does not take Malaysia's hot-humid climate and the issues concerning carbon emissions in full account (Mohd Sahabuddin and Gonzalez-Longo, 2015). The regulations establish that the minimum size of openings for natural ventilation purposes in residential buildings should not be less than 10% of the total clear area of the room (UBBL, 2013), a requirement which remained unchanged for 33 years. There have been recent developments concerning the use of green rating tools in Malaysia, which are helping to improve the sustainable design of buildings and the health of their occupants. This paper reviews these existing regulations and green rating tools and explores the full potential for natural ventilation in Kuala Lumpur, in order to substantially reduce carbon emissions while ensuring a healthy and comfortable internal environment for the occupants of high-rise residential buildings.

Identifying the critical issues for natural ventilation in consolidated urban areas

Kuala Lumpur accommodates 81.5% of the total number of high-rise buildings in Malaysia, and half of these buildings are residential buildings (CTBUH, 2016). Although most of these buildings were initially designed as naturally ventilated, the majority of their occupants have included inefficient mechanical ventilation to achieve indoor cooling (Aflaki et al., 2016). Other capital cities in the SEA region, such as Singapore and Bangkok, have also experienced the same problem (Aldossary et al., 2016, Oswald and Riewe, 2013).

The three common factors associated with indoor discomfort and unhealthy environment in high-rise residential buildings in SEA cities are high air temperature, high air pollution and low air movement. The high ambient air temperature resulted from urban heat island effects, is the result of the combination of direct solar radiation, diffused radiation from the sky dome and reflected radiation from both adjacent buildings and hard surfaces in urban areas. It has increased heat penetrates into indoor spaces through convection, conduction and radiation mechanisms (Chenvidyakarn, 2013, Nave, 2012).

The high levels of carbon emissions are directly linked to increments in temperature (Lucon et al., 2014). The scientific report of Climate Change Scenarios for Malaysia 2001-2099 produced by the Malaysian Meteorological Department (MMD) in 2009, has projected a temperature increment of 1.1^{o}C to 3.6^{o}C by 2095 in Peninsular Malaysia. It has also been recorded that the average dry-bulb temperature in Kuala Lumpur in 2015, was 27^{o}C and that by 2050 this figure is expected to increase by 1.2^{o}C (ESRI, 2015, MMD, 2010 - 2016).

As in many other cities, air pollution causes unhealthy environment in Kuala Lumpur's urban areas, as it contains airborne particulate matter and toxic gases from fuel vehicles, (Leh et al., 2012). Moreover, during the dry months of February to March and June to August in the past few decades, haze has become a regular event in Kuala Lumpur (Payus et al., 2013, Elsayed, 2012).

Both temperature and pollution issues are worsened by the insufficient wind movement in Kuala Lumpur, potentially reducing the possibilities of natural ventilation (Payus et al., 2013, Tahir et al., 2010). The city's average monthly wind speed was 1.1 m/s in 2015 (MMD, 2010 - 2016); this low figure together with the high air temperature, the presence of airborne particulate matter and urban roughness produce a series of challenges in order to implement natural ventilation strategies in buildings within the city. These factors have been so far considered in isolation and it is necessary to analyse them in an integrated way to inform the design which allows achieving a healthier and more comfortable indoor environment in high-rise residential buildings in an urban area in hot-humid climate such as Kuala Lumpur while reducing carbon emissions (Fig. 1).

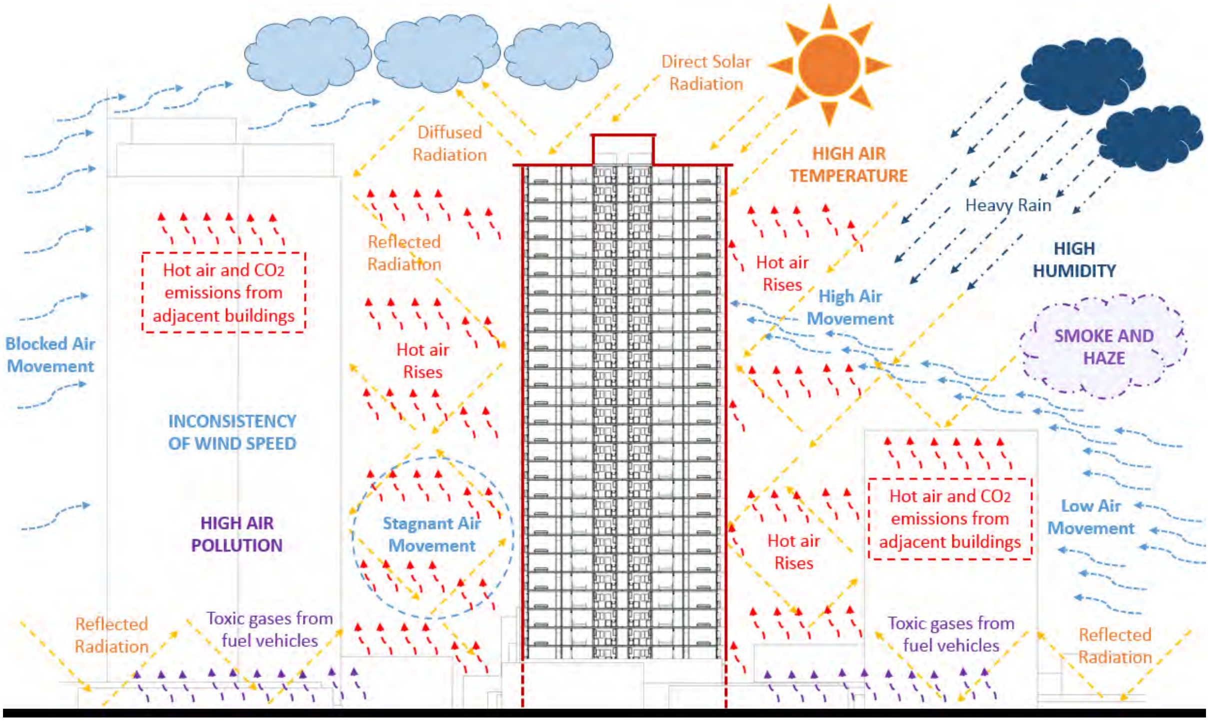

Figure 1: Factors affecting natural ventilation in a typical high-rise building within an urban area in hot-humid climate

Current Building Regulations, Standards and Green Ratings

The mandatory building regulations in Malaysia are called the 'Uniform Building By-Laws' (UBBL) 1984 and are contained within the 'Street, Drainage and Building Act' (SDBA) 1974. The requirements for natural ventilation in residential buildings are established in the 3rd part of the regulations: 'Space, Light and Ventilation' under clauses 39(1), 39(4), 40(1) and 40(2). However, they are only concerned about the proportion of windows and size of light-wells and there are not more specific regulations on achieving healthy indoor air quality.

Clause 39(1) states that '*every room designed, adapted or used for residential purposes, shall be provided with natural ventilation by means of one or more windows having a total area of not less than 10% of the clear floor area of such room and shall have openings capable of allowing a free uninterrupted passage of air of not less than 5% of such floor area*' (UBBL, 2013). Clause 39(4) determines that '*every water-closet, latrine, urinal and bathroom* *should be provided with natural ventilation by means of one or more openings having a total area of not less than 0.2 sqm*' from the room's total area (UBBL, 2013).

For buildings that are more than 8 storied high, clause 40(1), establishes that the minimum size of light-wells should be not less than 15 sqm, being the minimum width 2.5 meters and clause 40(2) requires the minimum size of each light-well for lavatories, water closets and bathrooms shall be 5.5 sqm and 2.0 meters minimum width (UBBL, 2013). These could not provide an acceptable ventilation by natural means in high-rise residential buildings where weaker stack effect due to lower temperature differences and heat build-up at the top of the light-wells might happen at certain levels (Prajongsan, 2014, Kotani et al., 2003).

Concerning energy use, UBBL 1984 only refers to the Malaysian Standard 1525:2014 - 'Energy Efficiency and Use of Renewable Energy for Non-Residential Buildings', which proposes several passive design strategies for natural ventilation such as cross ventilation and stack ventilation. However, the standard only suggests using CO_2 sensors to control indoor air pollution. For indoor comfort cooling in air-conditioned spaces, this standard recommends the maximum air movement of 0.7 m/s and air temperature of 24^oC to 26^oC.

Malaysia, like many other countries, has recently developed several green rating tools. Three most popular green rating tools used by both private and public sectors, are the Green Building Index (GBI), the Green Real Estate (GreenRE) and Malaysian Carbon Reduction & Environmental Sustainability Tool (MyCREST). However, only GBI and GreenRE have been used for residential buildings so far (MGBC, 2014, REHDA, 2015).

The first green rating tool used in Malaysia was the GBI, initiated in 2009 by a private organisation, the Malaysian Green Building Corporation (MGBC, 2014). Until October 2015, approximately 327 buildings have been rated by GBI and 41% of them are residential (MGBC, 2017). Although the tool refers to UBBL 1984 for minimum percentage of openings, in its latest version for 'Residential New Construction' published in 2014, some natural ventilation strategies have been proposed. These include the provision of light-wells to promote the stack effect (as we have seen already considered by UBBL), open plan layouts to promote cross ventilation, shading devices or overhangs to protect windows from sun radiation and naturally ventilated public spaces. This rating tool also encourages the use of low Volatile Organic Compounds (VOC) materials and finishes to reduce the indoor air pollutants, but there is no minimum air movement and indoor air temperature recommendation.

Another private organisation, the Real Estate Housing Development Association, created GreenRE in 2013 (REHDA, 2015). This tool proposes several strategies to enhance natural ventilation in residential buildings. In addition to the strategies previously proposed by GBI such as the use of open plan layouts to promote cross ventilation and the provision of public spaces naturally ventilated, GreenRE encourages a more appropriate orientation of buildings, so that they face prevailing winds. The latest version of the tool, 'Design Reference Guide for Residential Building and Landed Home' published in 2015, recommends a provision of no less than 0.6 m/s average air movement in indoor spaces (REHDA, 2015) and avoiding VOC materials to achieve good indoor air quality. As in the case of GBI there are no recommendations for the minimum percentage of openings or indoor air temperature set.

MyCREST was created by a collaborative effort of several government agencies such as the Ministry of Works, Public Works Department of Malaysia (PWD) and the Construction Industry Development Board Malaysia (CIDB) in 2016 (CIDB, 2016). This document is at the moment available only for non-residential buildings. In order to maintain good quality in the indoor air, this tool requires that all naturally ventilated spaces should be '*permanently open to and within 7.6 meters of operable wall or roof openings and that operable area is at least*

4% of the net occupiable area' (CIDB, 2016). This figure is much lower than the 10% required by Clause 39 in UBBL 1984 and researchers have considered that the minimum opening percentage in high-rise residential buildings should be not considered equally and should have a variety of sizes depending on the location and height (Mohd Sahabuddin and Gonzalez-Longo, 2015). MyCREST proposes that the minimum average of air movement for naturally ventilated spaces should be no less than 0.6 m/s. Similar to the other two green rating tools, MyCREST considers that the sources of air pollution are mainly from materials that contain VOC only (CIDB, 2016).

Table 1: Comparison of natural ventilation strategies in the laws, standards, and green rating tools in Malaysia

	PARAMETERS (Established) (Latest Version)	**UBBL (1984) (2013)**	**MS:1525 (2001) (2014)**	**GBI (2009) (2014)**	**GreenRE (2013) (2015)**	**MyCREST (2016) (2016)**
EXTERNAL	Suggest minimum percentage (%) of openings of the clear floor area	10%	-	-	-	4%
	Suggest minimum percentage (%) of uninterrupted openings	5%	-	-	-	-
	Suggest recesses, shading devices, or overhangs	-	√	√	-	√
	Suggest louvres and wing walls	-	√	-	-	√
	Use vented skylights	-	-	-	-	√
INTERNAL	Suggest to promote ventilation through adjoining rooms	-	-	-	-	√
	Suggest internal air speed	-	*0.7 m/s	-	>0.6 m/s	0.6 m/s
	Use cross Ventilation	-	√	√	√	√
	Implement open plan arrangement	-	√	√	√	√
	Suggest roof space be ventilated	-	-	-	-	√
	Suggest to use mechanical equipment	-	√	-	-	√
	Provide light-well or wind chimney to promote stack effect	$15m^2$ (> 8 stories)	√	√	-	-
	Suggest internal air temperature	-	*24-26°C	-	-	-
ETC	Suggest all public spaces should be naturally ventilated	√	√	√	√	√
	Provide wind direction table	-	-	-	-	√
	Suggest buildings should face prevailing winds	-	√	-	√	√
*****	For residential buildings	√	-	√	√	-
	Suggest passive method to reduce airborne particulate matter from incoming air intake	-	-	-	-	-
*For air-conditioned spaces						

This entire situation in the current scenario is concerned about the regulations and green rating tools, needs some clarification concerning the parameters they consider. Table 1 shows the comparison of natural ventilation strategies in the regulations, standards and the green rating tools used in Malaysia, as discussed above. Although there are significant improvements, in particular, the development of the recent MyCREST tool, Malaysia needs to address the need for a revision of its building regulations so that residential buildings are designed to minimise their carbon emissions and to improve the health and comfort of the occupants.

Learning from the Vernacular Architecture

In the residential buildings at tropical regions cooling is more important than heating. According to the chapter of 'Buildings: Mitigation of Climate Change' in the 5th Climate Change Assessment Report produced by the Intergovernmental Panel on Climate Change (IPCC) in 2014, residential buildings in tropical regions could lower the carbon emissions by introducing a design that could maintain indoor comfort temperatures without using any mechanical equipment. The clear precedent is vernacular houses, which design have succeeded in achieving cooling and comfort (Lucon et al., 2014). Although, obviously, they were not built in a dense urban context such as Kuala Lumpur.

In the case of traditional houses in Malaysia, it took hundreds of years to refine a well-adapted design to the local climate. The key factors for achieving healthy indoor comfort in Malaysia's rural areas are the integration of building form, the use of lightweight materials and green surroundings. Large overhangs, for example, prevent direct solar radiation and rain from entering the houses and timber-gap-floor on stilts promote fresh air intake from beneath the floor. High pitched roofs with ventilation at the top exhaust warm air by the stack effect. Lightweight materials immediately release solar heat (Lim, 1987), and large openings on the facades, which effectively balance the external and internal air temperatures (Kubota and Toe, 2015). An integrated natural ventilation strategy informed by these vernacular precedents has a great potential to reduce carbon emissions directly and at the same time ensuring the health and increased comfort of the occupants.

A study on the possible adaptation of these vernacular strategies to a modern social housing building has proved that an appropriate envelope and layout configuration could achieve the acceptable operative temperature of 25.2^{o}C to 27.2^{o}C, increase the indoor air movement up to 80% and reduce 67% of the carbon emission as well as energy consumption (Mohd Sahabuddin and Gonzalez-Longo, 2015). This study, which has introduced the concept of an 'Airhouse' standard for hot-humid climates, established that the percentage of openings in the building façade should be between 15% to 45% depending on the height of the residential units, increasing or decreasing the area depending non the height of the residential unit. A full-height opening configuration was proposed with three elements and these are - main windows, fixed louvres and adjustable louvres. Fixed louvres are introduced at the upper level of the internal walls to allow air to circulate throughout the units at every time. The proposed standard has also suggested that the depth of rooms should be decreased to enhance cross ventilation and the overhangs should be provided to protect all windows from solar radiation at any angles. Further studies are being carried out to refine and validate the standard.

Conclusion and recommendations

Although current building regulations, standards and green rating tools have proposed many natural ventilation strategies in Malaysia, they have not been able to acknowledge the current and future climatic conditions of Kuala Lumpur. At the same time, they are not able to address the required improvements in occupant's health and comfort as well as the reduction of the carbon emissions. The UBBL, especially the clauses 39(1) and 40(1) that regulate sizes of openings and light well requirements, were informed by British building standards and have not been reviewed and further researched in accordance with local climate conditions. These clauses, which have been used for 33 years without revision, should be revised and improved in order to reduce carbon emissions while ensuring occupant's health and comfort. Likewise, the standards (MS1525:2014) and green rating tools (GBI, GreenRE and MyCREST) have failed to devise strategies that could reduce airborne particulate matter and toxic gases as well as to prevent convective, conductive and radiative heat from entering and permeating high-rise residential units in Kuala Lumpur.

As per the clause 39(1), the minimum size of openings for ventilation purposes in a residential building in Malaysia should not less than 10% of the total clear area of the room. However, this sole figure seems to be inappropriate to provide ventilation and filter airborne particulate matter from entering indoor spaces in high-rise residential buildings due to different heights factor. Clause 40(1) of UBBL sets the requirement for a light-well of 15 sqm in buildings higher than 8 stories, which could not provide an acceptable ventilation by natural means in high-rise buildings due to weak stack effect and the absence of wind-force ventilation. Further studies should be carried out to test the appropriateness of these requirements to achieve suitable ventilation while ensuring the health of the building occupants and increase comfort levels in indoor spaces.

Building regulations in Malaysia, which are concerned about the natural ventilation, should be revised in order to reduce energy consumption and carbon emissions as well as to deal with the challenges of heat stress and air pollution which affect the comfort and health of the building's occupants. This revision should take into consideration the critical conditions, which allow for natural ventilation to enhance air movement, reduce the airborne particulate matter and maintain the acceptable operative temperature. By improving the regulations and maximising the potential of natural ventilation, high-rise residential buildings in Kuala Lumpur would become healthy and comfortable places to live in and great contributors to the mitigation of climate change.

Acknowledgment

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Design to Thrive

What heavy weight buildings in hot climates can tell us about their thermal performance

Philippe H. Saleh[1], Rosa Schiano-Phan[1] and Colin Gleeson[2]

[1] Department of Architecture and Environmental Design, Faculty of Architecture and Built Environment, University of Westminster, London, UK. w1510075@my.westminster.ac.
[2] Department of Property and Construction, Architecture and Environmental Design, Faculty of Architecture and Built Environment, University of Westminster, London, UK.

Abstract: Concrete, masonry walls and stone finishes are high density materials and have high thermal capacity, they are referred to as heavy-weight construction or thermal mass, which is the main construction type in Lebanon. Although thermal mass construction is usually recommended in hot climates in order to reduce internal temperature fluctuation, its actual thermal behavior in Lebanon is not well documented through direct observation, relying instead on its theoretical performance. This study's main objective is to characterize the actual thermal performance of such construction, in the context of building occupancy and intermittent A/C usage. The paper starts with a brief introduction of the residential typologies in Lebanon followed by the description of the three thermally monitored apartments, in use or empty, located in one same neighborhood of Beirut, Lebanon. The monitoring was undertaken during summer 2015 using hourly data loggers. The analysis of the recorded data provides a clear and empirical understanding on: 1. how heavy weight buildings interact within the hot and humid climate of Beirut; 2. how the effect of regulating the internal thermal fluctuation is shown; and 3. what are the most influential factors that would further enhance thermal performance of thermal mass construction.

Keywords: Thermal-mass, building-performance, residential, Lebanon, warm climate

Introduction

This paper investigates the thermal performance of apartment buildings within the coastal climate of Beirut, Lebanon. Three apartments are here presented out of a sample of five, which have been thermally monitored during summer 2015. The analysis of the recorded data provides an empirical understanding on how typical residential buildings using heavy to medium-weight construction perform within the warm and humid climate of Beirut. Furthermore, this analysis shows the effect of the thermal mass associated to the heavy-weight construction in regulating the internal temperature fluctuation, and the factors that can further influence and enhance the thermal performance of the typical Lebanese construction.

Typology

Two main types of residential units prevail in Lebanon, the detached house type and the apartment building. The apartment typology is the most common, located in buildings of four to eight floors. The average area for a small apartment is 120sqm including two bedrooms, a family den, a kitchen, main living and reception area and two to three WCs (CDR, 2004). Open balconies are an intrinsic part of the apartment, however they are commonly glazed and turned into conservatories in order to provide extra space (Melki, 2009).

A/C is extensively used for cooling, to the extent that finding a free running, occupied apartment to monitor is difficult. The individual split-system A/C is the most commonly used type.

Thermal Mass

The term Thermal Mass refers to any material that has the capacity to absorb, store and release heat (Littlefield, 2007; Szokolay, 2004). Concrete, masonry walls and stone finishes are high density materials with high thermal capacity, hence the term heavy-weight refers to that type of construction, which is the main construction type in Lebanon. Thermal performance of heavy-weight construction in hot climates is described as taking longer to warm up when exposed to solar gains and slower to respond to temperature variation (Littelfield, 2007; Szokolay, 2004). In the same way, it takes longer to cool down and loose the extra heat. This stored heat will dissipate during the night, when air temperatures are lower. This situation is ideal to maintain a comfortable indoor temperature when the temperature difference between day and night is considerable. Furthermore, Szokolay (2004) considers it a practical free-running solution to keep internal conditions within comfort. When it comes to expressing the thermal properties of thermal mass, the U-value is not relevant, instead the time lag, decrement factor and admittance or Y-value (Szokolay, 2008) are more appropriate for such materials. The time lag, expressed in hours, is the delay between the ambient temperature peak and the peak temperature of the space where thermal mass is applied. The decrement factor is the ratio of the actual heat reaching the thermal mass, and the heat that would be post emitted, and, since it is a ratio it is non-dimensional. The admittance or the Y-value expresses the thermal mass ability to store heat within itself, while ambient temperature fluctuates, it is expressed in W/m^2K although the same unit as the U-value, yet it expresses a different physical property, the larger it is the less internal thermal fluctuation is to be expected.

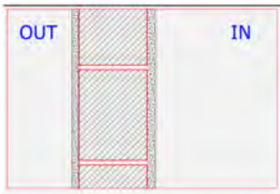
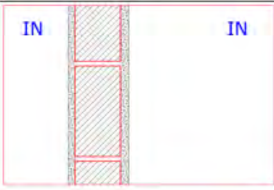
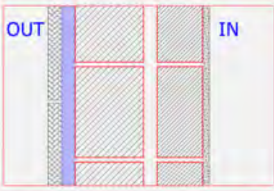
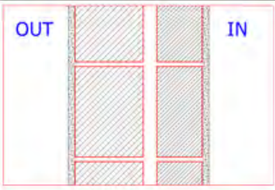
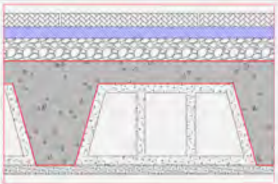
With the absence of local references for any of the above thermal property values of the different local construction materials and types, both Szokolay's (2008) and CIBSE Guide A (2006) are used to calculate or to find the nearest construction match for U-values and Y-values of the different types of walls and slabs encountered within the monitored buildings, as shown in the table 1. It can be noted that although the walls in apartment 3 have a better U-value than in apartment 1 and 2, all the apartments have similar admission values.

Methodology

During summer 2015, three different apartments have been thermally monitored, for a period of two weeks to three months, these are located within one of Beirut's suburban neighbourhood of Ain er-Remeneh, the period of monitoring stretched from August to October. The historical weather files for the entire monitored period is available from the main, official weather station, located at the nearby airport some 3 to 4 Km away.

The fieldwork was mainly based on the monitoring of thermal performance of selected rooms in each apartment, interviews of the occupants and observations. Instrumentation for the thermal monitoring of the various apartment included 16 Gemini Tiny Tag data loggers for Dry Bulb Temperature and Relative Humidity. Four of these included probe sensors specially recommended for outdoor monitoring.

Table 1. Ranges of U-Values and Y-values for the wall and slab constructions contained within the research

	Constrcution Type	Building	U-Value (W/m²k)	Admittance Y-Value (W/m²k)
	21mm Ext render + 150mm Hollow Concrete (dense) Block + 21mm Int Plaster	1 & 2	2.13	3.7
	21mm Ext render + 100mm Hollow Concrete (dense) Block + 21mm Int Plaster	1, 2 & 3 (internal partitions)	2.57	3.4
	30mm Stone Cladding 25mm Cement Mortar 150mm Ext Hollow Concrete (dense) Block 30mm Air Gap 100mm Int Hollow Concrete (dense) Block 21mm Int Plaster	3 (east)	0.54	3.4
	25mm External Render 150mm Ext Hollow Concrete (dense) Block 30mm Air Gap 100mm Int Hollow Concrete (dense) Block 21mm Int Plaster	3 (west)	0.55	3.4
	30mm Stone Tiling 25mm Cement Mortar 50mm Aggregates 230mm Hollow Concrete Slab Cast in-Situ 21mm Int Plaster	1, 2 & 3	1.96	5.5

Climate

Beirut is located on the eastern Mediterranean coast. Based on the Koppen-Gieger classification (Kottek et al; 2006), it falls within the Csa zone, which stands for warm temperate winter and no precipitation in the hot summer. From the representative Beirut weather file (Meteronorm 7), the following descriptive statements can be derived. Beirut has long hours of sun that provide high solar irradiation. Summer humidity fluctuates between 60 and 80% with an average above 70%, peaking during the night. August is the hottest month with maximum dry bulb temperature reaching 33°C and a minimum of 25°C. Furthermore, the diurnal difference ranges between 5 and 7°C. Summer months extend from June till mid-October, with an average monthly temperature ranging between 25 and 28°C, and maximum temperature reaching 33°C (July, August) and minimum 20°C (June, October). The average annual wind velocity is less than 3m/s with monthly averages varying between 2.5 to 3.2m/s.

Case Studies fieldwork analysis

Apartment #1 –Full time cooling

This 1960s east facing apartment building has five floors with 4 apartments per floor. In each apartment, the floors and ceiling slabs are tiled and plastered concrete respectively, whereas the walls are plastered hollow concrete blocks. Windows are single glazed panes with steel frames, which are, according to the occupants, permeable to wind, and thus infiltration is high. The monitored apartment is located on the third floor, and it was surveyed from mid-September till end of October, monitoring internal temperature in a continuously cooled space. The apartment is for a family of three, with all occupants spending much of their day at home. The apartment has an east orientation for the living and bedrooms. Individual , old window type A/C is continuously on in the living/dining space.

Apartment #2 – Mixed-mode cooling

This building was also built in the 1960s and it is made of 5 floors, with two apartments on each, the ground floor is for commercial use. The main façade where the living areas are facing is south-west oriented. Its eastern façade is blank and exposed. The building is made of concrete slabs, plastered hollow concrete block walls, and all the windows are single glazing with timber frames. The monitored apartment is on the fourth floors, hence an intermediate floor. The apartment has two bedrooms, one main living area, a dining area and a kitchen, for a family of four. Father is at work all day, as well as one of the sons, whereas the other, a university student is more often at home. Mother is mainly at home. Data loggers for dry bulb temperature are located in the living area, the bedroom and the semi outdoor space with a perforated lightweight brick called *clostra*. The monitoring took place between from August and early October.

The apartment has individual A/C units installed in each bedroom and the living-dining area. The latter one is seldom used, whereas the bedrooms' A/C are used during the night at random times and for varying length. Otherwise in the living area a fan and the open windows are used to provide some comfort from the heat and humidity. When A/C is used in whatever room, the internal timber door is closed in order to keep the coolness contained.

Apartment #3 – Free running, Unoccupied

This monitored apartment is within a newly constructed building and is still unfurnished and unoccupied. The building has an East orientation for the living areas, and is made of concrete slabs and double cavity hollow concrete block walls. As per the current planning regulation, the east façade is cladded with natural white and yellow stones; whereas the west facade is rendered and painted. Data loggers for dry bulb temperature are placed in the main living area on the east side, as well as in one room on the west side. The monitored phase spanned from August to the end of October. This apartment is on the 7^{th} floor of a 9-story building, hence an intermediate location, and since it is unoccupied, neither A/C nor any other power or heat source is available. Furthermore, based on the recommendation of the building owner, one data logger is placed in the staircase leading to the underground basement, an area that is never used by any of the building's inhabitants. This area is ventilated through the main entrance gate without being hit by direct sun light.

In table 2 below the different cooling modes of each room is listed as well as the calculated overall room admittance, which sums all the products of the respective surface areas of external and internal walls along with the floor and ceilings multiplied by the corresponding admittance of each, and is expressed in W/K (Balcom, 1983).

Table 2. Recap of each monitored room cooling mode and the corresponding calculated weighted Y-values

	Internal Space	Cooling Status	Σ [Y*Area] (W/K)
Apartment #1	Dining	Full time	**180**
	Entrance	Full time	**257**
Apartment #2	Dining	Seldom	**311**
	Bedroom	Mixed mode	**374**
Apartment #3	Living	Free running	**348**
	Bedroom	Free running	**197**

Results

The current study investigated the thermal performance of existing apartments with different envelope construction, cooling patterns and living habits.

Apartment 1 has continuous cooling which pushes the indoor temperatures almost always within a 29°C average, yet due to poor envelope performance, high infiltration levels, and undersized old A/C, there is a discrepancy between the cooling set point at 26°C and the actual recorded temperature, which is shown to fluctuate above 29°C in the early afternoon when the sun start to hit the external west wall, and windows nearer to the data logger (Dining temperature - days 266, 267 and 268). The Entrance area presents a temperature profile that is more stable as not affected by direct solar gains. On the night of day 268 to 269 the cooling is turned off till late morning, without windows opening, but the expected high infiltration is taking the temperature trend parallel to the outdoors' with 1K warmer, whereas once the sun is up and till midday internal temperatures are considerably cooler from 3 to 4k

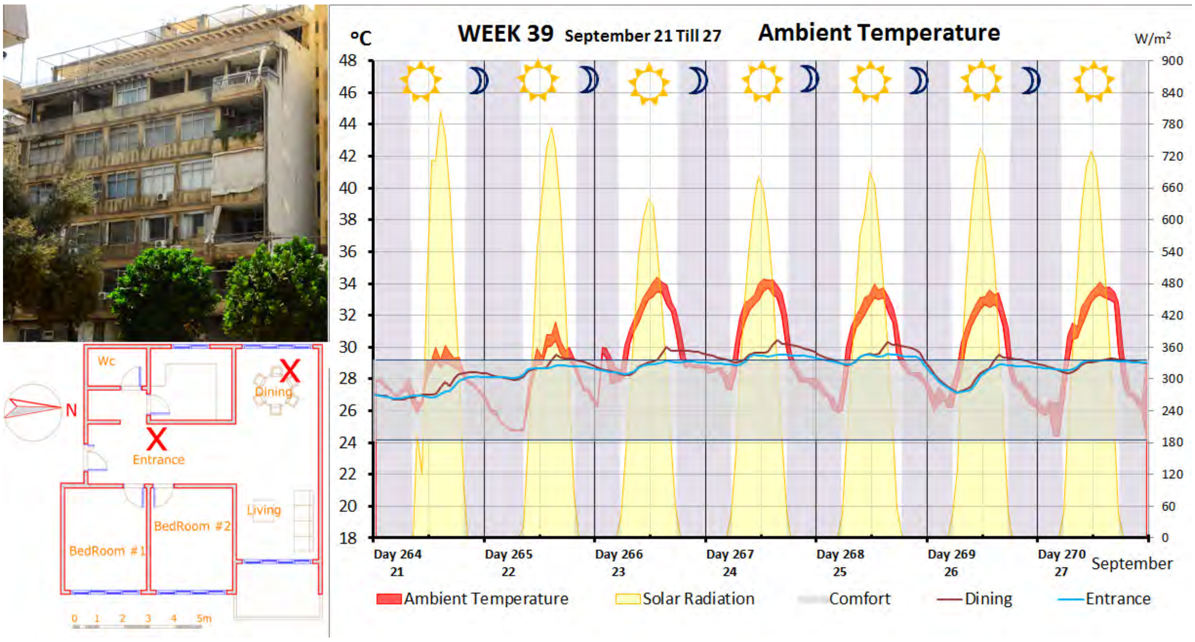


Figure 1. Building of apartment 1 in continuous cooling mode with the corresponding plan showing location of data loggers, along with the thermal graph for week 39

Discussions of observation are focused herein on week 32, August 1 till 7 for apartments 2 and 3.

Apartment 2 in mixed mode cooling, three spaces have been observed: the bed room, the dining area and the *clostra*, which is a sheltered semi-outdoor space. Extended night cooling and limited daytime cooling provide the bedroom with temperatures lower than the external temperature, yet when there is no night cooling, internal temperatures are 2 to 3 K higher and following the same trend as the external temperatures. Cooling in the dining area is limited to no more than a couple of hours on alternate days. Observations show that maximum day and night temperatures have limited fluctuation of no more than 4K when outdoor ambient air temperature fluctuation reaches 9K. Internal daytime temperatures are down to 4K lower; whereas night temperature are warmer than outside temperature. The *clostra*'s thermal behavior is similarly 2 to 3K cooler than the outdoors' day temperature and 2K warmer during the night, with a day/night fluctuation of 4-5K higher than the living area.

Looking closely on day 216, both the time lag and the decrement factor are clearly shown: the former is the time difference (horizontal axis) between the day's ambient peak temperature after midday (1pm) and both the *clostra*' and the dining's peak a couple of hours later (around 3pm). The latter is the temperature difference from the 34^{o}C peak ambient temperature to the 31-32^{o}C peak temperature of the dining and *clostra*'s.

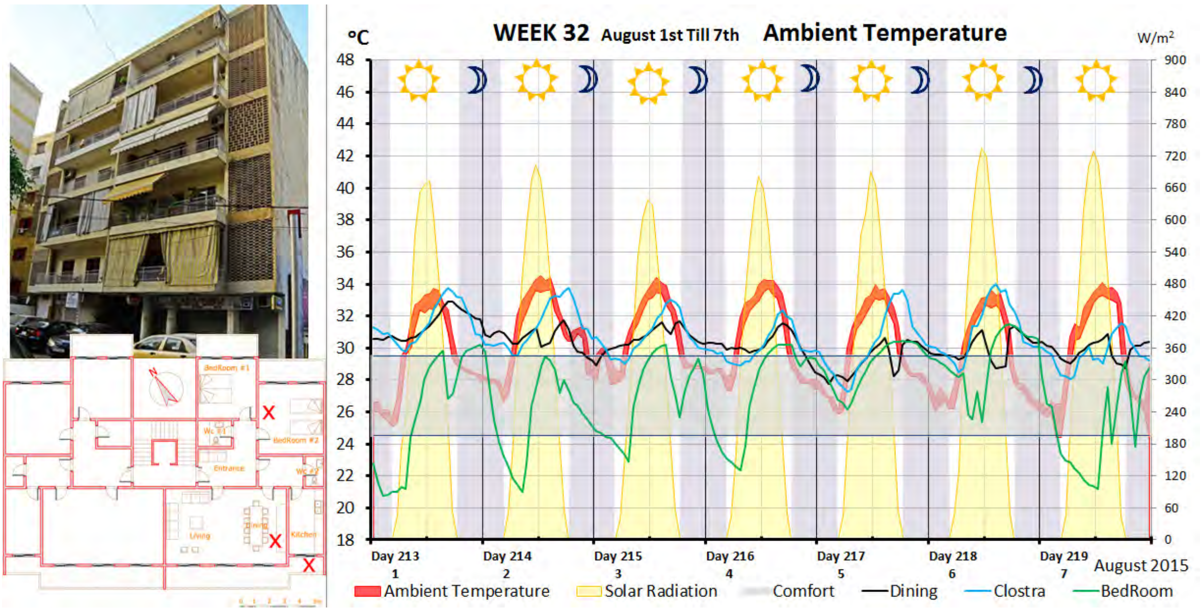


Figure 2. Building of apartment 2 in mixed mode cooling with the corresponding plan showing location of data loggers, along with the thermal graph for week 32

In the free running and unoccupied **apartment 3,** the dry bulb temperature of the living area and bedroom are recorded where the windows are kept 50% open. In addition, ground floor staircase leading to the basement is also monitored. Sun hit the living area data loggers directly around early afternoon and gave instantaneous thermal peaks, yet that aside, the temperature trend can be read with 2K cooler during the day and 3K warmer during the night, with a fluctuation ranging between 2 and 3K. As for the bedroom's day temperature, they are similarly 2K cooler than the outdoors but 4K warmer than the night temperature, and the daily fluctuation is only 2K; much less than the outdoors' 9K fluctuation. This reduced fluctuation is the effect of the surface admittance. Finally, the air temperature within the staircase leading to the basement is cooler than the apartment temperature and 2K cooler than the outdoors during the day and 2K warmer during the night with max fluctuation of 3K.

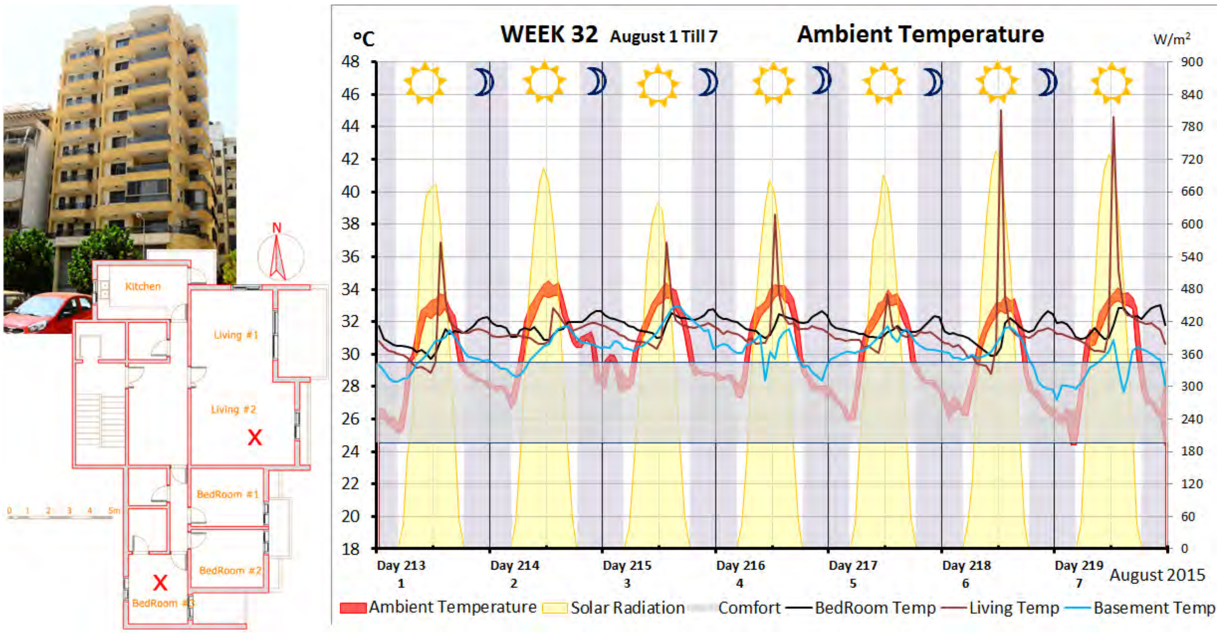


Figure 4. Building of apartment 3 free running with the corresponding plan showing location of data loggers, along with the thermal graph for week 32

Discussion

The above observations are the direct result of the thermal mass all those buildings have in common, combined with some ventilation. This is happening with high infiltration while A/C is running in apartment 1, windows are open when A/C is off in apartment 2 and apartment 3 has no A/C and windows are kept open. Based on the official weather station the wind is more often still during the day, whereas during the night it can reach an average velocity slightly above 2m/s, this creates low night air exchange varying from 0.9 to 4.5ach as shown in figure 5 and based on Szokolay (2008) and Brown (2001) calculation methods. Those air exchange are not enough to flush all the stored heat within the thermal mass during the night.

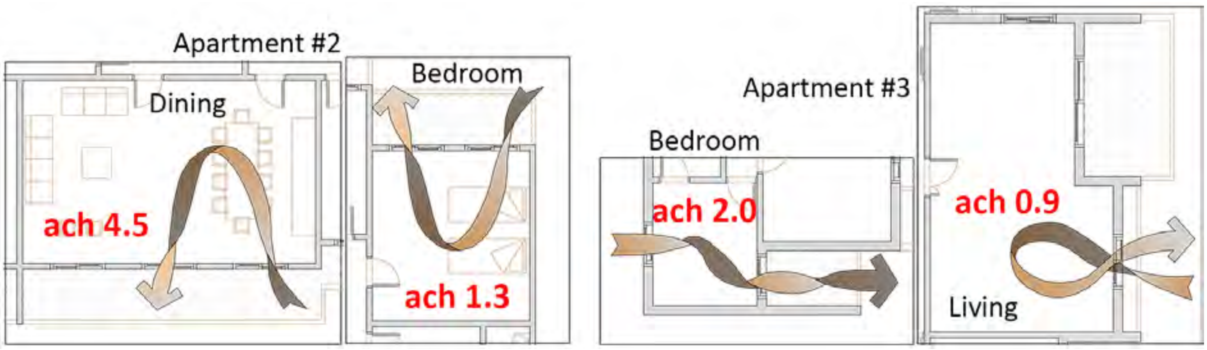


Figure 5. Calculated air exchange per hour (ach) in the different monitored rooms of apartment 2 and 3, based on the recorded air velocity of 2m/s. Also, the visualization of the internal air patterns is shown.

Concentrating on dining room of apartment 2 and living of apartment 3 with the data shown in table 3, the following observations can be stated: (1) the effect of almost similar Y-Values and weighted admittance responsible for heat storage within the envelop is shown in the day's cooler internal temperature. (2) The insufficient night air exchange is not able to get the internal temperature as low as the outdoors; yet the higher air exchange in the dining is maintaining its temperature cooler than in the living with much lower air exchange. (3) This lead to the role of the envelope's U-value with apartment 3 low value of $0.54W/m^2K$ that is not aiding in the dissipation of the night remaining heat and thus contributing to warmer internal temperature comparted to apartment 2 which has higher U-Value at 2.13W/m^{2}K, that are further helping in heat dissipation.

Table 3. Comparative data for dining room and living area

Apart	Room	Orientation	**Y-Values** (W/m^{2}K) Walls	Slabs	Walls **U-Values** (W/m2K)	Weighted admittance (W/K)	Air exchange (ach)	**Cooler** Δt Day (K)	**Warmer** Δt Night (K)
2	Dining	South	3.7	5.5	2.13	311	4.5	4	2-3
3	Living	East	3.4	5.5	0.54	348	0.9	2	4

Conclusion

The paper reviewed the theoretical background of the thermal mass effect, as reducing the internal thermal fluctuation and keeping the day temperature cooler than the outdoors. It also explained the relevant physical properties that best express the thermal behavior of thermal mass and calculated the admittance or Y-value of the encountered relevant construction in the different monitored cases. Next the research thermally monitored three different apartments within the same Beirut neighborhood, with different cooling modes. Based on these observations the research showed how exposed thermal mass with Y-values ranging from 3.4 and 5.5 W/m^{2}K combined with limited night air exchanges varying from 0.9 to 4.5 ach are able to: (1) reduce the internal temperature fluctuation from the outdoors' 9K to less than half at 4 and even 2K, (2) keep the internal day temperature between 2 to 4K cooler than the outdoors' but also are (3) not able to flush the night excess heat with night temperature 2 to 4K warmer than the outdoors'. (4) Reduced night time ventilation and low wall U-values of 0.54 W/m^{2}K reduce the effect of night thermal flushing compared to a higher U-value of 2.13.

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Design to Thrive

A review of minimum U-values for Lebanon and the associated effect of Internal gains

Philippe H. Saleh[1], Rosa Schiano-Phan[1] and Colin Gleeson[2]

[1] Department of Architecture and Environmental Design, Faculty of Architecture and Built Environment, University of Westminster, London, UK. w1510075@my.westminster.ac.

[2] Department of Property and Construction, Architecture and Environmental Design, Faculty of Architecture and Built Environment, University of Westminster, London, UK.

Abstract: Since 2005 various publications have proposed different U-values to be used in Lebanon to reduce the buildings' energy demand, creating confusion and a lack of specific and authoritative recommendation. Moreover, the various thermal performance guidelines are not easily comparable due to unexplained basic assumptions and guidance on the calculation of internal gains.

This study has two interrelated objectives: a) test the most appropriate U-values for the climate of Beirut, b) study the consequence of increased internal gains have on the cooling energy load in low U-value construction. The paper does dynamic thermal simulation of the various U-values from local and international sources. The analysis allows the comparison and ranking of these various U-values based on the overall yearly energy demand for cooling. This is followed by a sensitivity study where a range of increased internal heat gains are inputted onto a low and a high U-value model to demonstrate that an increase in internal gains results in both models having the same cooling loads. Low U-values under this scenario due not result in a lower annual energy load.

The study concludes that, although finding the appropriate U-value for hot climates seems uncontroversial, the effect of internal gains must be taken into consideration. Hence the importance of having consistent and harmonized national and regional benchmark values for U-values and internal gains.

Keywords: Internal gains, U-Values, Hot Climate, Lebanon

Introduction

Building energy codes in general identify U-values as their principal method of annual energy reduction. A number of local and international publications have proposed different U-values to be used in Lebanon and similar climate zones to reduce the buildings' energy demand for cooling and heating. With both national and international construction actors operating in Lebanon, this situation creates confusion and shows a lack of specific and authoritative recommendation, with many guidelines being provided by organizations with no regulatory or mandatory power. Moreover, the various thermal performance guidelines are not easily comparable as most of these publications either ignore or offer without justification guidance on the calculation of internal gains. Further complicating matters, Lebanon has four recognized climate zones where Beirut, the center of most development is exemplified by a coastal climate of a long hot and humid summer without precipitation and warm short winters (TSB, 2010 & Kottek et al; 2006). In addition, the dominant construction materials making up the building stock is almost entirely stone, concrete and related combinations, all fitting within the definition of heavy weight construction. Based on known benefits of thermal mass (Nicol et al, 2012; Szokolay, 2004; Yannas 1994; Littlefield, 2007), one would expect to find a very good example of low energy performing buildings. Yet it appears that Beirut's occupants, indoors summer thermal comfort is highly reliant on mechanical cooling.

Objectives

This study has two interrelated objectives: a) test, through thermal modeling, the impact of these different U-value standards on the annual energy load for Beirut and b) to study the consequences of increased internal gains on the annual energy load in low U-value construction.

Methodology

The paper reviews the impact of different U-values from the two editions of the Thermal Standard for Buildings in Lebanon (2005 & 2010), those from the Lebanon Center for Energy Conservation LCEC guidelines (2014) and finally, those proposed for similar climates. This is followed by energy benchmarks listing for yearly cooling and heating values, before checking the internal heat gains available values. The first phase of the research starts with dynamic thermal simulations to test the proposed U-values in conjunction with typical local construction materials in Beirut. The analysis allows the comparison and ranking of the various U-values based on the overall yearly energy demand for cooling and heating. In the second phase of the research a range of internal heat gains are inputted onto a low and a high U-value models to demonstrate that as these increase, the impact is disproportionate on and resulting in both models having similar cooling loads.

The study concludes that, although Building codes provide U-values for hot climate construction, an apparently uncontroversial focus, the need for providing internal gain parameters is of equal consideration for modeling annual energy demand in hot climates.

Envelope U-Values

U-Values for each of the external walls, the roof and the windows, from the different local and international sources are listed in table 1. The values are considerably different from one source to the other: the roof U-values range from 0.1 to 0.75 W/m^{2}K, the external walls from 0.18 to 1.62 W/m^{2}K. In both cases the lowest values are the LCEC guidelines (2014), which did not specify any value for the windows. Otherwise those windows U-Values range from 1.81 to 6.2 W/m^{2}K which encompass triple glazing with low-e coating; to single glazed windows, as well as the intermediate double glazing. When the source gives the values in imperial units for U-factor, a conversion factor of 5.678 is used to change into SI units to U-Values (ASHRAE 2013).

The yearly cooling and heating energy demand benchmarks from sources where available are shown in table 2. The standard values are defined by the LCEC (2014) as "business as usual" in reference for any typical building without energy consideration, it is set for residential at 118 kWh/m^2 per year out of which only 3 are for heating. On the other hand, the benchmark value for a building to start being considered as energy efficient is 80 kWh/m^2 per year.

Table 1. All U-Values from different local and foreign sources expressed in W/m^2K

	Title	Year	Roof	Walls	Window	Notes
Lebanon	**Thermal Standard for Buildings**	2005	0.57	2.1	6.2	
	Thermal Standard for Buildings	2010	0.71	1.6	5.8	Till 25% Window to Wall area ratio (WWR)
				1.6	4	For 26 -35% WWR
				1.26	3.3	For 36-45% WWR
	Thermal Insulation Market in Lebanon [1]	2011	(3.2cm)	(1.2cm)	N.A.	Data given in thickness
			0.58-074	1.59-1.62		Calculated U-Value
	LCEC Guidelines on Preparing Technical Proposal for Non-Certified High Energy Performance Building	2014	0.1-0.15	0.18-0.31	N.A.	
Mediterranean	**RT2005 H3[2]**	2006	0.34	0.45	2.6	
	Tunisia ZT1[3]	2008	0.75	1.2	6.2	Low Window to Floor area ratio (WFR)
				1.1	6.2	Medium to High WFR area ratio
				0.8	3.2	Very High WFR area ratio
Int'l Codes	**ASHRAE 90.1.2007 (Zone 2 A, B)**	2007	0.27	0.70	4.26	Window U-Value for up to 40% Wall Area
	International Energy Conservation Code [4]	2015	0.15	0.71-0.44	1.98	Values of Roof & Walls converted from R-values, converted to SI[5] U-Values of Windows converted to SI

[1] Calculated U-Value based on XPS insulation thickness. Density 26-75Kg/m3 and R=0.026-0.037 W/m.K
[2] French Thermal standards for H3 Zone: Mediterranean area of south France
[3] Tunisian Norms for Private Buildings ZT1 zone which is the Mediterranean area of North East Tunisia
[4] R-Values Converted to U-Value by U=1/R; Value of Windows given in U-Value
[5] All U-values converted to metric value by multiplying by a conversion factor 5.678

Table 2. Yearly energy values in $kWh/m^2/year$ standards and benchmarks for residential

Title	Year	Residential Standard	Residential Benchmark
RT2005 H3*	**2006**		80**
Thermal Standard for Buildings (Lebanon)	**2010**		80
LCEC Guidelines on Preparing Technical Proposal for Non-Certified High Energy Performance Building (Lebanon)	**2014**	118	80

* French Thermal standards for the H3 Zone : Mediterranean area of south France
** Based on fossil fuel heating (as opposed to electrical heating which has higher value)

When it comes to the internal heat gains from occupants, lights and equipment, LCEC & CIBSE values are shown in table 3 below. LCEC mentions the occupants' in terms of W/m^2 whereas the lighting's is given in total energy per year kWh/m^2, values which are then calculated to fit in the table in terms of W/m^2.

Table 3. Internal gains values and ranges of values including totals expressed in W/m^2 from LCEC and CIBSE

Source	Type	Occupants	Lighting	Equipment	Total
LCEC	Residential	5	1.5*	n.a.	**6.5**
LCEC	Offices	14	1.9*	n.a.	**15.9**
CIBSE	Offices	5-6.7	8-12	15	**28-33.7**

* Values Calculated from 13 and 17 kWh/m^2/year

Building sample

For this study, an actual apartment is taken as a reference for the dynamic thermal simulation. It is located in the Ain er-Remmeneh area, on the outskirts of Beirut. Made of 5 floors, with two apartments on each, and a commercial ground floor, it has a south-west main orientation for the living areas and blank exposed walls to its eastern and western façades. The building is made out of concrete slabs, plastered hollow concrete block walls, and all the windows have wooden frames. Each apartment is 110sqm and is made out of two bedrooms, one living and dining area, kitchen, two WCs and one entrance functioning as a small family living. The apartment is occupied by a family of four. The occupants' behavior along with the schedule of lighting and equipment are recorded to be inputted as the internal gains in the thermal simulation model.

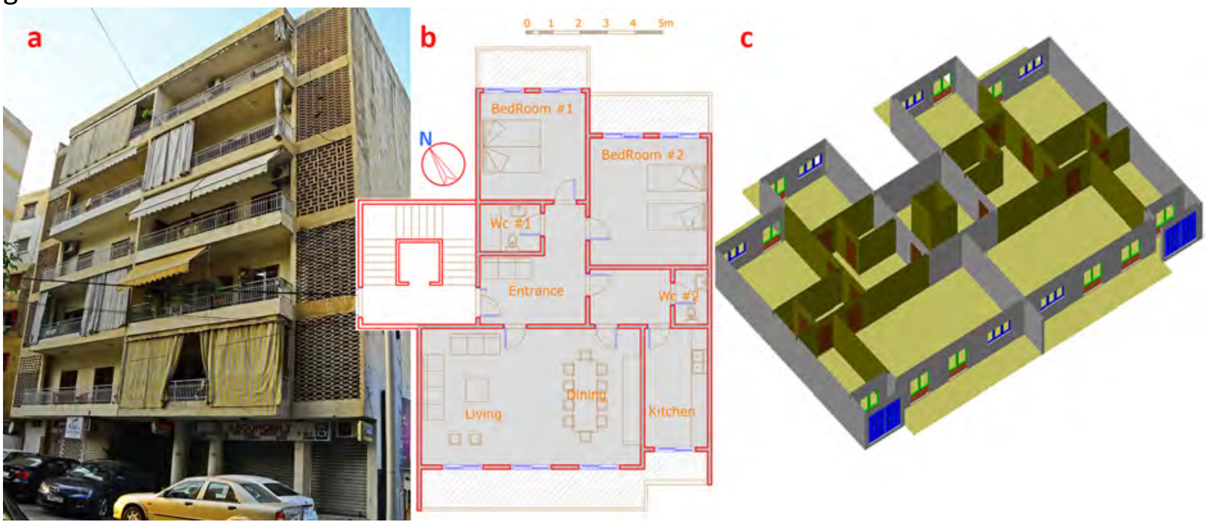

Figure 1. (a)The Building used as a model for the simulation; (b) Typical plan of one apartment; (c) 3D axonometric of the thermal model showing one entire floor with both apartments.

Thermal Simulation

The EDSL TAS 9.3.2 thermal simulation software is used with the Bayrouth weather file 2000-2009 (Meteonorm 7). Four typical floors are modelled, each with the two adjacent apartments. The orientation is kept the same with the living areas facing South-West, and cooling and heating yearly values per area are shown herein for the third and fourth floors, with the fourth considered as the top floor and third as intermediate floor.

The annual loads for cooling and heating are calculated for intermittent mode only when users are there, and occupancy is based on the observed apartment users' living patterns and remained unchanged in all the different simulations with the same input for internal gains as observed and computed to be 4.8 W/m^2. Cooling temperature is based on 24^{o}C set-point and 50% RH threshold; whereas heating temperature is set at 20 ^{o}C. The internal heat gains from lighting, users and equipment are based on the observed, recorded and calculated data, and consequently are kept the same throughout. Although each reference has different U-value for windows, the simulations are keeping the same value of 5.68 W/m^{2}K for all the simulation in order to limit the variable, and focus on the basic argument of the research.

Results

Run #1 The cooling and heating annual loads using the different U-values from the references are shown in figure 2. The cooling load is always considerably higher than the heating load, up to three to four times larger. Although this difference is expected in a hot climate like Beirut's, nevertheless what is not expected is to see that local references miss to highlight the important role thermal mass plays in reducing the internal temperature fluctuation, but instead focus on insulated construction.

The top floor has higher heating and cooling values than the intermittent floor with the cooling values differences, much more pronounced: they start at a maximum of 10% higher with the base case at 57 and 52 kWh/m^2

The cooling yearly values for the intermediate floor changes between 48 and 54 kWh/m^2 for the LCEC values and the TSB2005 respectively. Whereas the top floor cooling values ranged between 49 and 57 kWh/m^2 with again the LCEC and the base case values respectively.

All runs reached values lower than the 80 kWh/m^2 set as a benchmark (table 2). This again raises the issue of the relevancy of the local sources when no specific guidelines or ranges of values for any of the many parameters involved in the thermal simulation are available (table 3).

Run # 2 This run carries the research to its second phase where the basic internal gains of 4.8 W/m^2, used in the first runs, and which were based on actual observation, are now raised to 2.5 times, and 5 times larger (table 4). The TSB2005 and the LCEC models are used for highest and lowest initial cooling load at 54 and 48 kWh/m^2 respectively.

The calculation of the cumulative total internal gains in all the different zones from users, equipment and lighting combined is done in two steps: starting with the total energy from these gains expressed in kWh/year, then this value is divided by the 365 days of the year, the 24 hours of the day and 110sqm of the total area, to have a final value expressed in W/m^2. Noting that the total energy is calculated by inputting the area of each zone with a specific schedule along a with a heat value also expressed in W/m^2.

Comparing the raised values of the internal gains to the available limited references, shown in table 3, both the base and the 2.5 times at 4.8 and 11.9W/m^2 respectively appears to be relatively lower than the expected at 6.5 and 15.9 W/m^2, even if compared to an office rather than a residential. Similarly, the 5 times larger value is still less than the expected range in offices varying between 28 and 33.7W/m^2. As a note, internal gains can change by having more people in the room, or even having the unprotected window allowing the unaccounted sun rays to penetrate the room at any time of the day.

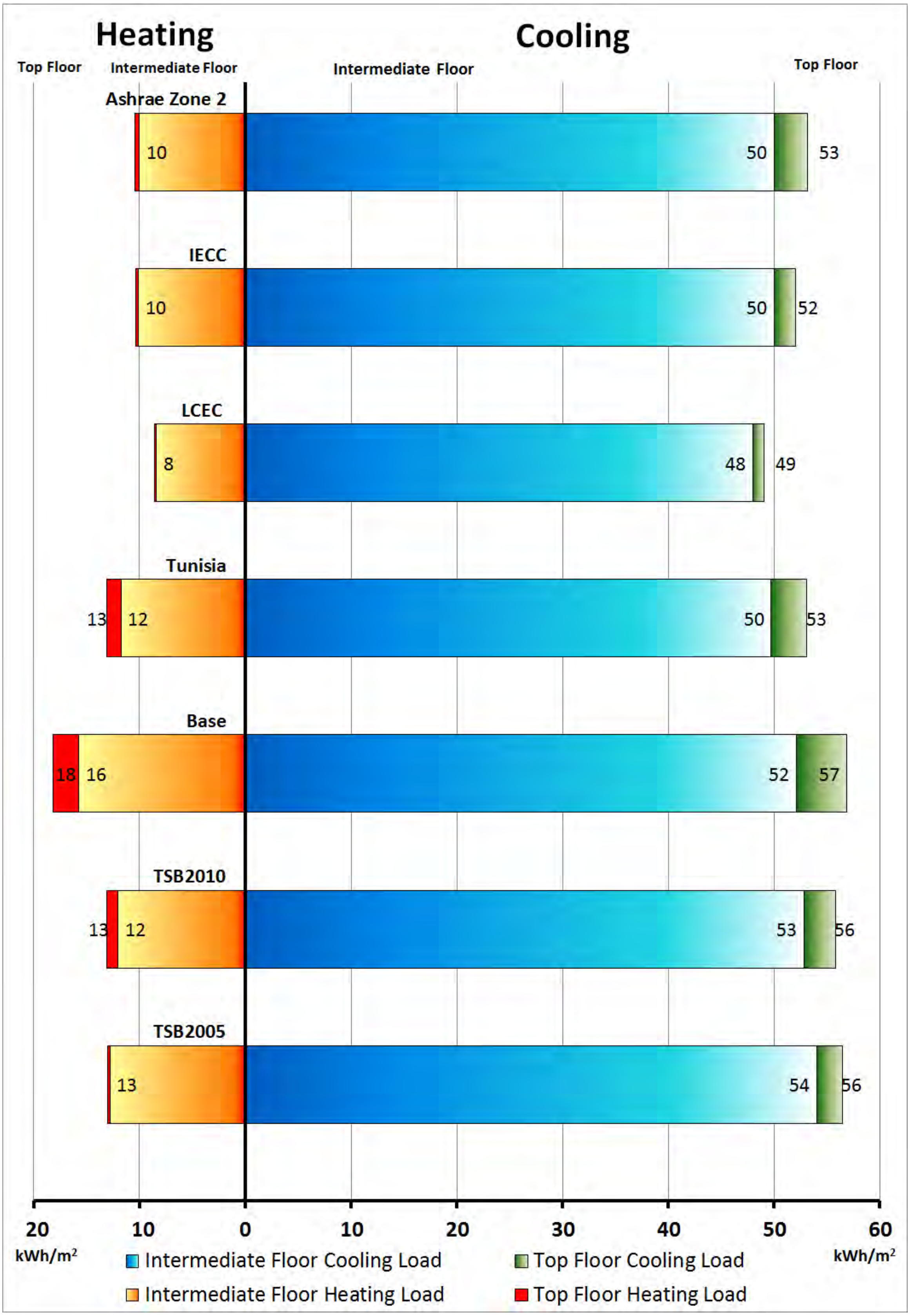

Figure 2 Overall summary of the cooling and heating load based on the different U-values from local, regional and international sources for a 110sqm residential apartment in Beirut.

Yet what should be noted here, is the critical point where low U-values construction is not performing well, when internal gains are high. In this case the percentage difference between the TSB and LCEC models are decreasing with the increase of the internal gains. Starting at 13% for the base case drops directly to 2% with the 2.5 time increase and reaches minus 4% difference.

Table 4. Showing in the first two columns the increasing internal gains in total yearly and daily per area with the available benchmarks, followed by the corresponding energy values for both the LCEC & TSB along with the percentage difference between both.

	Internal Gains			Energy Cooling Values		
	Total kWh (per Year)	**Daily Total** (W/m^2)	**Benchmark (Table 2)** (W/m^2)	**LCEC Base** (kWh/m^2)	**TSB Base** (kWh/m^2)	**% difference** (LCEC/TSB)
Base	4622	**4.8**	6.5	48	54	**13%**
x2.5 Internal Gains	11556	**11.9**	15.9	83	85	**2%**
x5 Internal Gains	23112	**24.2**	28-33.7	160	153	**-4%**

Conclusion

The paper reviewed the numerous U-values from different local and international sources, through thermal modeling, and carried on studying the consequence increased internal gains have on the cooling energy load in low U-value construction. In the first part and based on the thermal simulation the following statements apply: (a) cooling is typically 3 to 4 times higher than the heating, (b) cooling loads of the top floor range between 49-57 kWh/m^2 and are up to 10% higher than in intermediate floor ranging between 48-54 kWh/m^2. (c) all energy values are well below the 80 kWh/m^2 value set as a benchmark for a building to start being considered low energy. As for the second part when internal gains are increase 2.5 times, but still kept within the given range of values from local and international references, the difference between the previously lowest and highest energy model is reduced from 13% to only 2%. When they are increased 5 times, the difference becomes negative 4%, hence the previously best performing model with the low U-Values is now consuming 4% more energy than the model with the high U-Values. Finally, the paper concludes that set benchmark for internal gains are important for comparative studies, and more emphasis should be given for the effect thermal mass has on regulating the internal temperature in hot climates such as Beirut's.

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Energy sufficiency in buildings, a synonym for passive and low energy architecture (PLEA)

Pouya Samani[1], Hugo Santos[2] and Eduardo de Oliveira Fernandes[1,3]

[1] Institute of Science and Innovation in Mechanical and Industrial Engineering (INEGI), Porto, Portugal, psamani@inegi.up.pt;
[2] Institute of Science and Innovation in Mechanical and Industrial Engineering (INEGI), Porto, Portugal, hsantos@inegi.up.pt;
[3] Faculty of Engineering, University of Porto, Porto, Portugal, eof@fe.up.pt

Abstract: PLEA has promoted, for over 35 years, all avenues for energy sufficiency in buildings through the wise exploitation of 'sound architectural' design potentialities. From the millenary approach of vernacular architecture, particularly relevant in the Mediterranean basin, to energy sufficiency, a clear necessity now appears for designing and retrofitting buildings by expanding the PLEA perspective. That is an opportunity to undergo a new pathway for reducing energy use in buildings, going beyond efficiency, by exploring the potentialities of passive approaches to comfort through design. The concept of sufficiency, when and where applicable, must play its preemptive role in reducing energy needs to their strictly unavoidable levels and, consequently, reducing the CO_2 emissions associated with the building sector. Faced with these, the authorities have an obligation to be clear in what regards the priority and the values of sufficiency and efficiency, i.e. first sufficiency and then efficiency. While their result is the reduction of CO_2 emissions, those two approaches implicate very different means: the sufficiency is intrinsic to the building location, design and construction, while efficiency is related to add-on procedures whose expected outcomes are frequently defeated by a rebound effect.

Keywords: energy sufficiency, designing with the climate, adaptive comfort concepts

Introduction

Buildings, representing 40% of primary energy use and 35% of the global greenhouse gas emissions, can and shall call upon decision makers and designers to play a fundamental role towards environmental sustainability. Human beings spend 80% of their lives within buildings where energy for thermal comfort and health are basic needs. Whenever a building, and particularly its envelope, is not duly designed, the result is frequently seen in, either higher energy needs or, conversely, unreached proper conditions. When correctly used, buildings should act as true extensions of the environment fully in dialogue with the local climate and using insulation and shading as needed but, in any case, always taking advantage of the Sun and local amenities. However, the modern society has led to large urban conglomerates where buildings became strongly dependent on mechanical heating and cooling systems, in effect isolating them from their surroundings and inhibiting their frequently beneficial dialogue with the climate in temperate regions. In these cases, thermal comfort and wellbeing of the occupants became dependent on strict technological paths requiring intensive energy use. Continued technological advances and recent climate change threats have only further stimulated the fulfilment of thermal energy needs exclusively through more and more efficient systems and equipment, while tending to decouple building design from indoor comfort and wellbeing (Santos et al., 2016).

The built environment has been the heart of social, cultural and economic development of human beings (Holtz, 1989). Moreover, as the center of human activities, the built environment is the key element on the road to sustainability (de Oliveira Fernandes, 2016). While the first buildings were mainly makeshift shelters to keep humans protected, the interface between the built and natural environments has undergone various changes. After the industrial revolution, there was a shift to an architecture dependent on additional technological systems due to new demands for space, mobility, privacy and socialization. In the United States, for instance, the living space per person has tripled in comparison to fifty years ago (Blackburn, 2015). Passive and Low Energy Architecture (PLEA) is founded on the principles of passive design and vernacular and bioclimatic architectures, seeking for natural and innovative techniques for sustainable architecture and urban design. The final aim of PLEA is to reduce the energy use and cost of buildings while maintaining thermal comfort for humans (Cole et al., 2010). Current trends in terminology put all of the energy-demand reduction strategies within the single encompassing classification of 'energy efficiency'. One could argue, however, that energy efficiency is only strictly applicable, by thermodynamic definition, to the cases where devices and equipment are used, i.e. when there is a defined ratio between energy input and output from a system. Yet, many solutions cannot adequately be defined or measured in this manner. When energy has the potential for such an impact on the environment, the rigor of language and technology becomes necessary. That is particularly relevant to PLEA.

In fact, passive architectural solutions and climate-aware design aim to reduce the needs for energy. In this case, the demand for final energy (i.e. the 'energy' that people pay for) is reduced not because the same output can be achieved with lower energy input (efficiency) but because the building architecture and physics make better use of the potentialities of its climate and specific location to reduce the upfront energy needs (sufficiency). Relying exclusively on energy efficient equipment to cope with situations that could have been adequately addressed through the design itself is not only non-intelligent by itself, but also unethical and, in the current case of climate change, absurd. Recent regulations in Europe are calling for optimum cost solution packages, implying that a cost-benefit analysis, based solely on investment cost versus savings on energy over the systems' lifecycle, can adequately represent the relative merits of the solutions. However, what experience has shown is that many of the simplistic calculations based on estimated energy savings tend to be quite disconnected from the real-world use of buildings and systems by people. A well-designed building, which relies mostly on passive solutions, is intrinsically more resilient to time and usage patterns than technical systems tend to be. The latter tends to be plagued by the rebound effect and to struggle more drastically with the typical peculiarities of individuals and cultures.

The efforts done by PLEA focusing on climate and natural energy resources suggests looking at energy sufficiency as a preemptive action before considering energy efficiency. Some authors, (Lysen, 1996) and (Van Den Dobbelsteen, 2008), prioritized energy demand reduction before considering renewable energy and efficient supply in the three stepped strategy "Trias energetica" toward sustainability. As it can be seen in figure 1, even the International Energy Agency (IEA) has explicitly recommended exploring energy sufficiency prior to energy efficiency and renewable energy towards low-energy and low-carbon buildings (International Energy Agency (IEA), 2013).

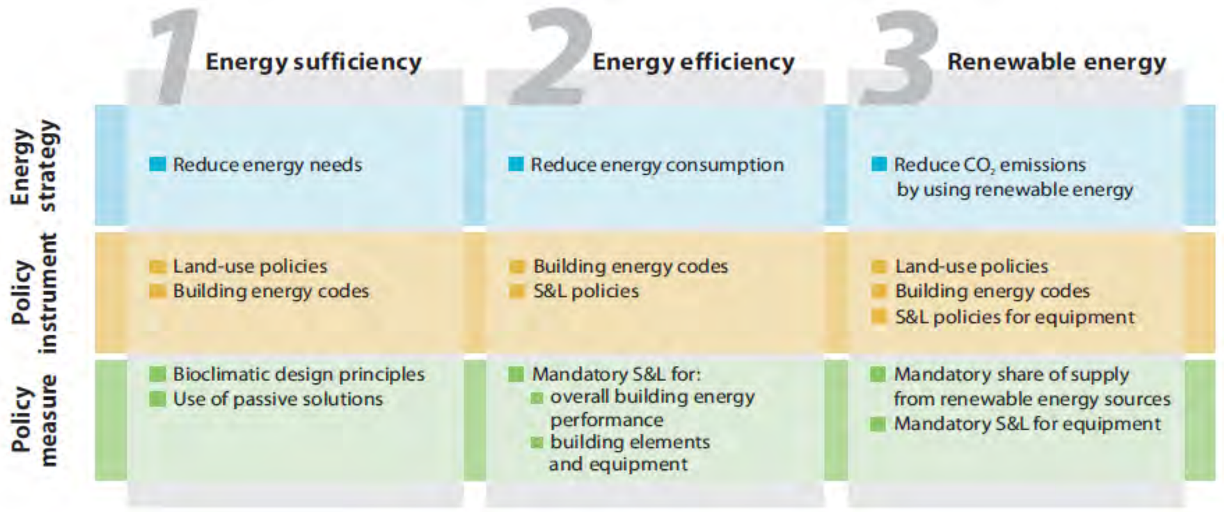

Figure 1. The path to follow at the design stage to achieve low-energy and low-carbon building by the IEA (International Energy Agency (IEA), 2013).

Since the early 80's, PLEA has been paying attention to the evolution of knowledge and technologies for exploring the Sun and the potentialities of the climate towards providing thermal comfort for occupants through sensible design and without any additional technical systems. While the former thermal comfort models were based on the indoor air indicators and suitable for air-conditioned buildings, they neglected various factors related to the occupants and their interactions with the building and the outdoor environment. Subsequently, adaptive comfort models were met taking into account other factors such as the expectation, preference and adaptation of the occupants. The adaptive thermal comfort models are vitally important in understanding the thermal performance of free-running buildings and identifying the potential of other strategies than through efficient technical systems. Adaptive comfort models are in tune and syntonic with the passive and solar approach proclaimed by PLEA. To clarify, that evolution of science and technologies are not at all in opposition to PLEA or to sufficiency, but what must be questioned is the 'one path' approach relying on hard energy technologies, its expected energy savings (ignoring rebound effects), and exacerbated automatisms to justify a rational that they do not have.

PLEA and energy sufficiency can be considered to be at a meeting point between science, technology and architecture towards sustainability. This meeting point not only does not limit the creativity of architects, but also supports them in designing more unique solutions without the need for technical interventions (de Oliveira Fernandes and Yannas, 1989). It is noteworthy that analytical tools, next to the existing complex, time consuming and non-accurate simulation tools, can be very useful in evaluating the design process, taking into account the engineering criteria for architects and vice-versa. Another important point is the local climate, culture, and the users' interferences that can drastically influence the building's performance. Therefore, the solution for each building is unique, rather than something that can be generalized and obtained in catalogues (de Oliveira Fernandes, 1989).

Energy sufficiency in buildings

There are two important points to note when conceptually differentiating energy efficiency and energy sufficiency. First, energy sufficiency creates a better framework to considering both quantitative and qualitative aspects when analyzing and defining the demand for energy. For instance, when a decision is made to promote public transport or carpooling instead of private cars (a sufficiency strategy), the demand for individual motorized mobility is shifted towards a shared ride that can be less desirable in terms of duration, space, time flexibility, route, etc. None of these aspects can be easily incorporated within an energy input vs. output analysis (or their associated costs) that would characterize the energy efficiency analysis. Instead, by focusing more on aspects such as the role of passiveness, system-dependent energy needs, and the users' behaviors, energy sufficiency should better accommodate the qualitative values of particular solutions and regulations.

Second, sufficiency is not only about directly asking or convincing users to reduce their energy use and influence their behaviors (explicit approach), but must mainly be about addressing modifications and adjustments in the built environment that result in natural decreases in energy needs even if the users are not aware of them (implicit approach). The latter is especially important in addressing sufficiency approaches within the building sector where the objective is to provide thermal comfort for the occupants with little or no requirements for technical interventions or user action.

Despite seeming to be clear-cut, the concept of sufficiency has yet not been fully recognized by scholars or policymakers (even in spite of the aforementioned IEA document). Many of its most relevant aspects are already well known and recognized but this knowledge is lost in the midst of a confusion in terminology and inexactitude of concepts that blurs the lines between passive and technical, ultimately drowning many of the opportunities that should have been explored. This is the case in most academic works discussing sufficiency by addressing it (inaccurately) as 'energy efficiency'. For instance, (Junghans, 2012) refers to principles such as sensible selection of the location and orientation of the building and its opening, thermal protection, solar energy use, etc. as 'energy-efficient' architecture. This is also found in the texts of regulations and directives, which ends up having a pernicious impact, opening the door to the more lucrative and frequently easier to implement technical solutions, despite being known that these may not be adequate for a particular setting. In this sense, the law fails to correctly direct actions by ignoring the nuances and failing to recognize and discuss the inherent differences between various options.

For the particular case of temperate climates, and particularly the ones in the Mediterranean basin, the sufficiency approach shows that the building must be designed, first, in a way that captures the useful energy from the sun, storing it effectively, and later diffusing it back indoors with little or no need for technical systems. Of course, proper shading must then avoid excessive solar gains in the summer, giving space to thermal inertia to keep the indoor temperatures cool during the hot days. The PLEA approaches mainly target these two parameters and many architecture examples worldwide can testimony to that. Designing small windows and doors is one of the evident examples of solar protection in vernacular architecture. There are various cases of using small openings in buildings today in southern Portugal, Italy or Greece. Enclosed balconies (which can serve as buffer zones to increase solar gain and prevent the heat loss) are explored in regions with cold and windy winter such as Beira Alta region in Portugal today. Examples of patios can be found even in the American continent, indicating how vernacular architecture has been conveyed between countries.

A common aspect between all these PLEA approaches is that they are mainly changes in the building arrangement and architecture (energy sufficiency), concerning the local climate, and effectively decreasing the energy needs before requiring any additional technical system.

Discussion and conclusions

It is known that energy efficiency approaches tend to struggle with the issues of rebound effect. Individuals tend to use many of the more energy efficient devices more frequently or more intensely, counting on their lower energy consumption (i.e. on their lower costs to run). The result is that energy savings are generally much lower than could be expected from the energy efficiency gains. Furthermore, in addition to this 'direct' rebound effect, there may also be an 'indirect' rebound effect when an increase in disposable income results in increased energy use in other activities by the same user or by others (Chitnis et al., 2014). Energy sufficiency approaches, particularly within the buildings sector (i.e. using PLEA's principles), per definition are free of any rebound effect, thus justifying giving it a higher order of merit than any of the technical energy efficiency options.

By reviewing the PLEA approaches, one can conclude that they contribute to energy demand reduction through sensible design of the building and its adaptability to the environment. It is clear that what the PLEA proposes must be unrelated with the technical add-ons at different stages of the energy flow or how efficiently useful energy fits to the energy demand (efficiency), but it is indeed all about reducing the demand itself to the actual needs (sufficiency). Therefore, the PLEA concept can be encompassed within the concept of energy sufficiency. Nowadays, the term 'efficient building' is increasingly being used here and there, most of the time in the wrong context. Likewise, energy efficiency has been widely addressed for PLEA approaches even in regulatory documents and standards. However, the common characteristic of the bases of PLEA (i.e. passive design and vernacular and bioclimatic architectures) is independency from additional energy-consuming HVAC systems, the stage where energy efficiency can play its role. It is noteworthy that in addition to addressing the building to reduce the energy demand (implicit approach), energy sufficiency also includes asking individuals to decrease their demands and avoid indulgence (explicit approach). What PLEA proposes, indeed, is comparable with the implicit approaches of energy sufficiency, but energy sufficiency is a broader concept than PLEA and embraces the user behavior as well.

While the concept of energy sufficiency proves to be effective and applicable within the building sector, nowadays many building designers and occupants disregard its potentials and rely on pollution-causing and costly options of HVAC technical systems. In this front, the regulations are of no help and are lacking in their role of directing appropriate decisions and actions. Currently, construction firms tend to replicate the same building from one country to another with very different climate, culture and user behaviors. The current standardization of buildings, around the globe, are mainly based on non-adaptive thermal comfort models and use of technical add-ons. For instance in the United States, the Green Building Council (USGBC) grades buildings through the Leading in Energy and Environment Design (LEED) certification. However, this certification does not accredit bioclimatic and passive solar designs. It is noteworthy that while it is possible to get the silver grade without any improvement in the energy performance of the building, it is impossible to achieve a high score in Energy and Atmosphere (EA) category of LEED without using mechanical systems (Shaviv, 2008).

Remarking the discussed order of merit of energy sufficiency over energy efficiency, the question then arises: why is there so much attention being paid to energy efficiency, and not enough to energy sufficiency? The first answer is that in that case, energy efficiency is encompassing all of the solutions of real efficiency and sufficiency. As described above, this ultimately results in bad solutions propagating inconsequently. Another interpretation is that energy efficiency is essentially linked to technology and technical options related to new and profitable opportunities. The existence of a demand leads to a market opportunity and decreasing that demand to the actual needs, would mean endangering various business opportunities. Energy sufficiency is not a solution from the past, but for the future. Understanding and recognizing the concept of energy sufficiency can lead to the evolution of the PLEA to an 'effective' or 'actual' PLEA as a preemptive approach to reducing energy needs and, consequently, cutting down the CO_2 emissions associated with the building sector.

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Design to Thrive

A Bioclimatic Reading About the Chandigarh Tower of Shadows

Heitor da Costa Silva

Faculty of Architecture, University of Rio Grande do Sul, Porto Alegre, Brazil,
heitordcs@gmail.com

Abstract: The objective of this paper is to discuss the qualifications of the built environment by the focus of Bioclimatic Architecture. The Tower of Shadows building designed by Le Corbusier and built in the Capitol of The Parliament in Chandigarh is the reference subject for the discussion. The discussion of the model is limited to the solar access in the buildings and the use of shading devices by means of the “brise soleil”. For modelling simulations it was used the “Sketchup” and “Energy Plus” softwares. The software “Sketchup” was used to produce an architectural model and the “Energy Plus” was used to test climate responses of the building. The outcome of the investigation point out that the building responds to Modern Architecture ideas as one archetype and for Bioclimatic Architecture the building illustrates a the solar control rule for environment adaptation of the building by means of solar control in the harsh climate of India.

Keywords: bioclimatic architecture, modern architecture, Tower of Shadows

Introduction

The Tower of Shadows is a peculiar building conceived by Le Corbusier to deal with the hot environment in Chandigarh, India, 30.73N Latitude and 76.77 Longitude. Also the material used a reinforced concrete structure and the general shape adopted for the building is iconic. Additionally the space has no specific use, it is said to be for rest. Le Corbusier described it as “a very open hall, very high and shadowy”. “Architecture has always been a transformation of material into human shelters in various types of natural and social spaces”.

Figure 1. Tower of Shadows, esplanade of Capitol, Chandigarh. (© Fernanda Antonio)

Figure 1 above shows the Tower of shadows view from East and far away in the picture is the Assembly Palace of Chandigarh.

About the Tower of Shadows

The Le Corbusier approach to control sunlight was considered “empirical”, due to the bad repercussion, regarding to thermal performance of the Salvation Army building, in Paris, in 1929. The low income building was completed in 1933. The main idea used in the concept of the building was a South facing glass wall, a double glazing system of air conditioning that never worked. The glass wall was replaced in 1952 after many summers with the residents dissatisfaction because of the overheated dormitories. This building played important role as experiment for Le Corbusier subsequent constructions. “These buildings played the role of a laboratory...”, it is Le Corbusier himself saying about to the Salvation Army (Armé du Salut) building.

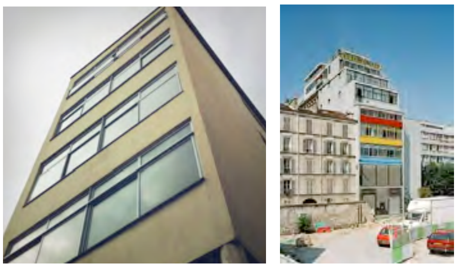

Figure 2. Salvation Army in 1933 and in 1952.

Examining the drawings in Le Corbusier “Ouvre Complete”, the first aspect that has called the attention at the starting of this study was the Tower of Shadows structure, the name of the building that Le Corbusier has given to the construction. Also, the grid used for the complex of edifices, in the area of the Assembly that received a 45°rotation angle used to situate the Tower of Shadows. This rotation provoked the building to adjusting exactly to the Cardial orientations. Also, examining some of the original drawings, there is a Sun Chart which shows the sun azimutes and altitudes in a 30N latitude that is shown close to the Tower of Shadows. See these remarks in figure 3 below.

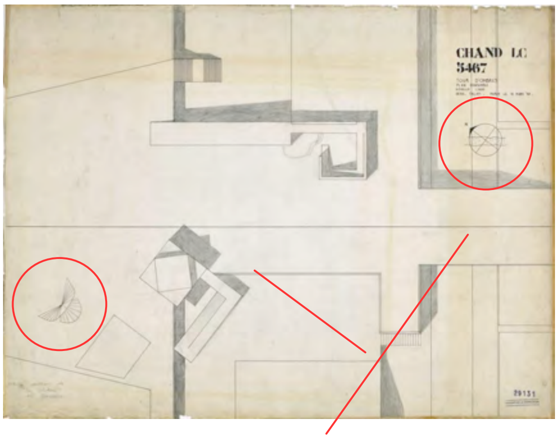

Figure 3. Site Plan for Tower of Shadows (original drawing from LCF, modified with remarks).

The evidences shown in figure 2 has lead to some questioning: - if the building is appropriate for solar control what happens with other climatic parameters? Besides the shadowing, how would behave other parameters affecting users, e.g. temperature?

Considering that the solar geometry and the apparent sun movement is the same, for a given latitude, one can say that Tower of Shadow would cast shadows similarly in Porto Alegre, Latitude 30.07 and 51.23 Longitude, but in South hemisphere.

The next step of the investigation was to develop architectural model using Sketchup to model shadows, this to understand the building geometry for further analysis with the aid of Energy Plus.

Architectural modelling and solar geometry for radiation control

The architectural modelling of the Tower of Shadows was made with the aid of the software Sketchup. Plans and sections of the building were searched to draw a three-dimensional model was specially designed to emulate shadows. The simulations were made specifying 30 Latitude. Also, the angles of the vertical elements of the façade were made variable, individually and in group to allow for variation in order to assess differing areas of shading inside the building.

A series of images were developed to emulate shadows hourly and seasonally, this to assess the efficiency of the “brises soleil” designed by Le Corbusier for The Tower of Shadows. The Figure 4, below shows the SW aspect of the model. This imagem allows visual assessment of the solar access inside the model that can be sectioned horizontally and vertically, so that is possible to “see” the sun inside the model, any time of the day along the year.

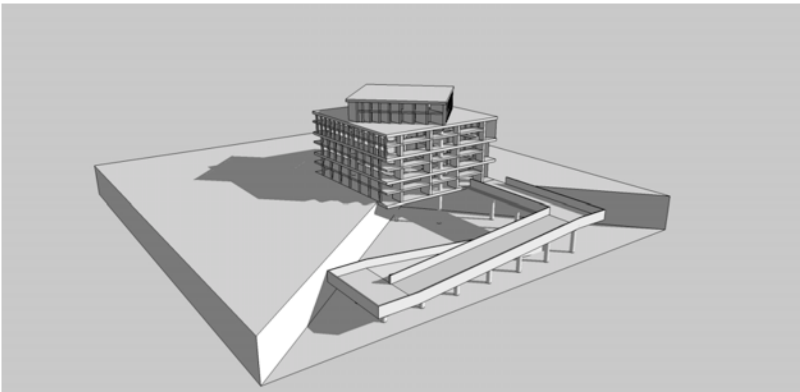

Figure 4. Tower of Shadows - solar geometry modelling for solar control and shading devices with Sketchup.

The modelling allowed to understand access of direct solar radiation. Two assertion can be assumed from the study: a) the building response to sun radiation with respect to shading devices is effective in the periods of high temperatures of summer and b) the vertical and horizontal dimensions of the devices are effective to promote shadows during the critical periods.

Thermal modelling for temperature assessment

The thermal modelling of the Tower of Shadows was made with the aid of the software Energy Plus. In order to attend to the structure of the thermal modelling programme varied adaptations were made in the architectural design. The EP+ software needs a “thermal zone” to identify internal and external environment. As the Tower of Shadows is a structure with the air environment coupled both internal and externally the thermal model had to be closed with a glazing surface.

The modification done to the thermal model altered not only the espacial criteria in terms of architecture but also the resulting internal temperatures, reflecting a environment similar to one winter garden.

The thermal modelling is trick because the EP+ is a powerful tool that requires detailed data for the thermal model and also the climatic data for Chandigarh and any mistake made in the input data can lead to severe errors can that invalidate either the current simulation or all the series of results. Neither physical data concerning the built material of the Tower of Shadows nor the climatic data with "epw" format were obtained for Chandigarh.

Figure 4 below shows results for the modelling produced running with climatic data for Porto Alegre 30S latitude. In this case the simulation produced was used in tentative maner to understanding internal behaviour of the building regarding temperature. Other simulations were developed for the same purpose but the model geometry do not seem to be appropriate some discrepancies were detected. A big effort is been made to produce a reliable model for this intent of understand internal temperature. However until now there is no reliable conclusions.

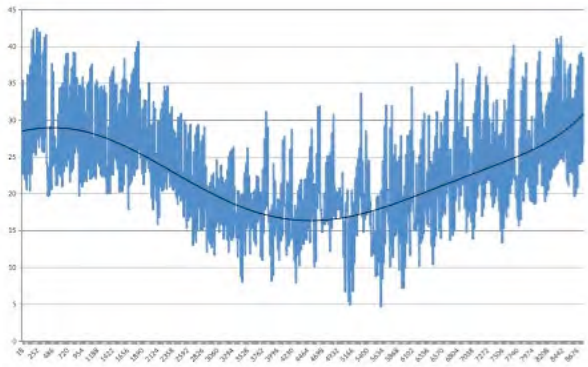

Figure 4. Tower of Shadows – thermal simulation for internal temperature.

Conclusion

The study has shown so far, that the building the Tower of Shadows by Le Corbusier is a very rich source for a bioclimatic reading exercise to understand design strategies to deal building adaptation to environment climates that demands for solar control and shading devices. Also, the Tower of Shadows allow precise investigation on solar control by means of shading devices, the so called "brise soleil" within the universe of the Le Corbusier life work. The building has proved to casts shadow inside its structure. Also Corbusier has given a proper name to the building calling it Tower of Shadows. It is not clear the internal thermal environment is always improved just because of the use of the "brise soleil". The simulations did to better understand the building thermal behaviour were severely limited because of the adaptations did to the model in order to have a comprehensive simulation. Several erros with the model were pointed out by the modelling EnergyPlus.

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Heritage and environment for new building in natural protected areas

Verónica Skvarca[1] and Silvia de Schiller[2]

[1] Research Centre Habitat & Energy, Faculty of Architecture, Design & Urbanism University of Buenos Aires, Argentina, arqskvarca@gmail.com
[2] Research Centre Habitat & Energy, Faculty of Architecture, Design & Urbanism University of Buenos Aires, Argentina, sdeschiller@gmail.com

Abstract: Architectural projects in protected natural areas responding to visitors, education and scientific programmes, require a specific environmental approach and design guidelines, with the aim of protecting and preserving these natural heritage sites, by controlling and minimizing impacts associated with human activities generated by buildings in highly sensitive sites. This paper presents the initiative to promote specific building guidelines in protected areas and national parks of Argentina, through the development of sustainability parameters to implement in new projects. The Nahuel Huapi National Park, Patagonia, Argentina, provides a base to study feasible procedures to implement principles and evaluate sustainability criteria to assess and qualify new projects. International references, were instrumental to develop sustainable building requirements, with emphasis on environmental values related to building design and management, together with innovation criteria for renovation, revitalization and recycling. The proposed Environmentally Responsible Design Methodology was applied to representative buildings providing case studies from the four stages of the National Park development process, to qualify and quantify sustainability issues relating buildings and environments, and analyzing evolution over time. This document emphasizes implementation of innovative approaches, for future interventions applicable to minimize building impacts on sensitive natural sites in the context of sustainability in architecture and environment.

Keywords: Sustainability, Design, Natural areas, Environment.

Introduction

National Parks, located in sensitive areas, aim to preserve the natural and cultural heritage of a nation for future generations. Therefore, they present a valuable test case as their presence not only ensures the conservation of the area involved, but also promote the spread of knowledge on sustainable development issues, provide innovative management practices in neighboring areas, and ensure the presence of an increasingly attractive recognition by national and international tourism industry as registered trademark of prestige. They also provide direct and indirect environmental services of great value to society as a whole, improving the quality of natural habitats.

The existence of protected areas shows the particular consideration of a country towards the care for present and future development. In this framework, National Parks have become icons of sustainable development representing real opportunities for growth, jobs and social equity, as well as stimulation of more dynamic regional economies.

A variety of natural and cultural values, together with immaterial issues, are displayed for visitors, discovering a series of economic criteria, according to international ranking, such as those established by UNESCO, ranging from the architectural isolated sites to well provided routes and cultural landscapes.

In Argentina, protected natural areas have not yet developed certification or assessment procedures to ensure the sustainability of their buildings. Considering the high environmental vulnerability of these sites, maximum care is required, particularly where vacant areas are detected for possible human interventions. In these cases the implementation of special measures to preserve the unique ecosystems is needed by generating and applying sustainability criteria in building projects, carefully combining new technologies and traditions.

The increasing numbers of visitors and flows of ecological tourism, searching for a direct contact with nature and spiritual satisfaction, is promoting a new scope for recreational activities. In this case “sustainable tourism” for visitors represents a significant experience, involving them in environmental issues and promoting eco-friendly practices. Currently, international standards and certification systems, such as BREEAM in the UK, CASBEE in Japan, LEED through the USGBC in the USA, Green Star in Australia, are proving useful criteria and instrumental tools. There is also the Green Globe certification, an specific system providing standards to support sustainability in travel and tourism, evaluating a company’s performance and impacts.

These standards provide a number of criteria and indicators as well as policies and procedures in line with sustainability certification programmes, established worldwide. In Argentina, a significant body of knowledge is building up and developing evaluation programmes related to policy studies and human behavour particularly relevant to provide support for these initiatives (Evans, J., 2010). These standards, originally focused primarily on urban areas, include studies and analysis seeking for the improvement of habitats built with minimum use of resources and low environment impact though achieving adequate confort, mainly by intelligent design and bioclimatic strategies. Sustainability requires a change of mentality, a shift in values towards new lifestyles. These changes may be able to enhance global interaction, environmental management, social responsibility and economic viability.

The new approach to sustainable design must recognize the consequences of each design option favouring natural and cultural resources at local, regional and global levels. According to the Declaration of Interdependence for a Sustainable Future “Sustainable by Design”, of the International Union of Architects (UIA), Chicago (1993): *"sustainable design integrates consideration of resource and energy efficiency, healthy buildings and materials, land use ecologically and socially sensitive and an aesthetic sensitivity that inspires, affirms and allows".* The UIA has also expressed in the Copenhagen Declaration (2009) that *"architecture must develop holistic methods, from the smallest scale to urban planning, not to mention the buildings, landscapes, natural environment and infrastructure elements essential to the continued creation of sustainable and livable future. An attentive and respectful design of forms, geometry and space strategy, associated materials, equipment and adequate functional distribution can reduce resource use, emissions of greenhouse gases and global environmental impact of 50 to 80 %".* This statement puts the value of responsible architectural design as a source of identity, diversity and pluralism, in accordance with UNESCO's declaration on cultural diversity, where it is declared a common heritage of humanity, source of exchange, innovation and creativity " assuming it is as necessary for humanity as biodiversity is for nature". (2001, Art.1)

Background of certifications

The qualifications and certifications add value to the sustainable building in the market. The objective of the certification systems is to provide an independent mechanism to verify the progress of sustainability in architecture. For this purpose, it is necessary to have the guidance of the designer during the design process, always considering transparency and reliability in the evaluation.

In the last few years, there have been concerns in the Latin American region related to the application of Sustainable Building qualification and certification systems, calling into question the criteria and methods used in systems developed and implemented in highly industrialized and highly developed countries. RESET model (Sustainable Building Requirements in the Tropics), a basic document developed in Costa Rica by the Institute of Tropical Architecture (IAT), designed to extend sustainability requirements to a wide range of buildings, prioritizing the Design and the sustainability potential of architecture. As stated in the Manual: *"Enhancing the design of architecture and engineering as a tool to achieve sustainability, will bring savings, independence and adaptation to the place. Adapting to the climate by recovering its attributes and renewable resources, strengthening the local economy, favoring the use of local labor and materials, and strengthening the culture that is updated and enriched with contemporary architecture that emerges from the traditions"* (2012:7).

This standard becomes a pragmatic tool that facilitates and revises project decisions, serving as an indicator and guideline, to incorporate responsible criteria with the environment and was designed for the evaluation of a building in its design, construction and / or operation stage. The results of the evaluation are determined in a percentage of achievement, that does not quantify emissions, nor savings of consumption in numbers; but reflects efforts made in the design and construction of the building.

Several documents analyze the current state of the situation and the evaluation of the advances, limitations and possibilities of sustainability certification of sustainable construction in the Latin American region. At regional level in Latin America, it is necessary to advance a series of considerations that allow the development of regional criteria and local instruments of implementation (de Schiller et al., 2003)

Environmentally Responsible Design Methodology

The use of sustainable criteria in National Parks implies less impact on natural sites to preserve in the most pristine way possible for present and future generations, through the translation of these strategies into effective measures of implementation. The effects of determining the degree of sustainability in architecture, has been designed a Environmentally Responsible Design Methodology (ERD), a product that is constituted as a qualification and certification system. Applying this Methodology, also collaborates in decision making at the moment of design, thinking about sustainability in architecture, with more design strategies than with technologies, deepening the potential of design, before adding technologies, only using them as a complement. This contributes to the conservation of the natural heritage, located inside and outside the National Parks of Argentina.

For their design, different qualities have been analyzed to consider specifically and locally the desirable attributes that make a construction project sustainable. This determination of attributes, not unique or exclusive, is oriented to an environmental responsibility of the interventions and propitiates actions that aim at a minimization of negative impacts. Ten key points are established which, in turn, have ten items to consider, through which the actions to be fulfilled are quantified. Through this analysis the percentage of the interventions can be calculated in percentage terms, while the desirable parameters for buildings are proposed within a space where the main objective is the conservation of nature. With these indicators, the sustainability actions of the project are measured, according to the following set of items that contribute to minimizing impacts. To the items indicated above, it is proposed to associate each of them with a quality attribute, which can be quantified (Table 1).

	ITEMS	ATTRIBUTE
1	Implementation and site.	Adaption to the site
2	Efficiency in the use of water.	Water, care and efficiency
3	Efficiency in the use of energy.	Energy, care and efficiency
4	Envelopes and materials.	Materiality, and enclosoures
5	Universal accessibility.	Universal accesibility in design
6	Natural conditioning, lighting and ventilation.	Naturality, lighting and natural ventilation
7	GHG emissions (greenhouse gases).	Emissions, Impact of GHG, Green-house Gases
8	Equipment	Capacity, with equipment
9	Usability	Operability, in the efficient use of buildings
10	Construction and deconstruction	Rationality of the construction processes

Table 1 – Attributes

In order to carry out the analysis and qualification of each project, characteristics are established, which configure each attribute, as detailed below:

- The **adaptation to the site**, it is considered of paramount importance to avoid the alteration of ecologically sensitive areas, maintaining the natural drainage systems, respecting the topography, making minimum interventions in the movement of soils, as well as the conservation of the existing arboreal species, adapting the Architecture to the site and not the site to the architecture.
- In the case of **water, care and efficiency**, it is considered the implementation of measures for the use and reuse of gray water for cisterns and toilets, with toilets with the option of half load. Consideration is given to design decisions that propose the recycling of gray water and its use in risk, as well as the reduction of the use of drinking water, collecting waste water, use of sanitary parts, faucets and accessories for consumption (with automatic wáter closing systems) and incorporation of elements that value water as a vital resource.
- In relation to **energy, care and efficiency**, the maximization of bioclimatic design strategies according to the Bioenvironmental Zoning of the Argentine Republic, IRAM Standard 11,603, prioritizing the local construction and material traditions, as well as the implementation of the project considering orientation, Sunning and wind protection or catching breeze. Actions that tend to use renewable energies and actions that minimize energy dependence, isolation of the soil to isolate it from the cold and / or snow are weighted.
- In the case of **materials and envelopes**, the use of local materials and the use of building materials with low energy demand for manufacturing, transport and

maintenance is preferred, considering the total or partial reuse of existing buildings. The use of toxic materials used in the treatment of timber should be avoided, using those certified throughout the chain of custody, not only from certified forests. The use of local and non-toxic materials, which can nobly return to the earth, and actions aimed at avoiding the use of solvent-based paints, favor the reuse and recycling of existing constructions.

- Through actions aimed at implementing **universal accessibility** measures in projects, it is considered mandatory to apply Decree 914 / of Law 22,431 modified by Law 24.314, National Accessibility Law. In public works, a universal accessibility design should be included, including the Use of Spaces and Services for All, and the Design for All Manual, incorporating adapted toilets, ramps, entrance doors with adequate measures, texts in Braille, Sound signals, and accessible parking, design decisions that effectively contribute to the story of sustainability within the framework of social equity.
- The attribute of N**atural, conditioning lighting and ventilation**, is related to actions that favor design strategies to enhance lighting and natural ventilation, considering the incorporation of the concept "access to the sun", sun protection in summer, thermal comfort of buildings and Visual to the outside. The application of vernacular criteria and the generation of intermediate spaces between the interior and exterior are evaluated, reducing the direct impact of the external climate.
- The item on **GHG emissions (Gases Greenhouse Effect)**, is related to designs that reduce these emissions. Measures are taken to promote energy efficiency measures for conserving heat in winter, sun protection in summer (avoiding overheating and consequent energy demand for cooling), adequate thermal insulation in walls and ceilings, and integration of passive and active systems.
- In relation to the saving **Capacity** in construction processes, the efficiency in the operation of the facilities is evaluated, reducing the demand for maintenance, including an efficient waste management and recycling.
- With respect to **Operativity** and its link to the efficient use of buildings, it is considered valuable that the buildings have use manuals and training programs for users and personnel operating the building. It possible to visualize the operation, management and use of the facilities, incorporating thermostats, sensors, meters, dimmers and other control devices, as well as the control of electricity and water consumption by premises or sectors.
- The attribute of **Rationality** is related to efficiency in construction processes, considering the measures that mitigate noise and dust, as well as unnecessary movement of materials. Likewise, they describe constructive procedures that assure the mitigation, control and elimination of pollutants to the soil and the conservation of existing organic land, establishing their management during the construction process, through their recovery, storage and reuse.

Universe of analysis, Nahuel Huapi National Park

The creation of the Park dated from 1903, when Perito Francisco Moreno donated the land to the Nation, an area of three square miles, located on the border of the Neuquen and Río Negro territories, on the west end of the arm Blest of the Nahuel Huapi Lake. The area became the heart of Argentina's first National Park, declared in 1922 as “National Park of the South”. In 1934 the National Congress passed the law creating the Nahuel Huapi National Park, incorporating a larger territory. Thus, Argentina became the third country in the Americas, after the United States and Canada, to have a National Park.

Located on the southern foothills of The Andes, in the Argentinean side of the northwestern Patagonia, the pioneering history of the Park soon become a heritage feature. Since the creation of the Nahuel Huapi National Park, a project was born with the aim of “urbanising” the region. A team of architects, Bustillo, Estrada and Césari, designed and built a series of buildings, including several within the site to establish a settlement which is now the City of Bariloche, along the lines of a general plan supporting local development. The architecture develops as a cultural expressions producing, according to the ideas of the time. Samples of varied cultural heritage from rural buildings made by local people who settled in the area before the creation of the Park, were covered with tiles, with little ornamentation and strong trans-Andean influences with intuitive bioclimatic features.

Study Cases

The proposed Environmentally Responsible Design Methodology was applied to representative buildings providing case studies from the four stages of the National Park development process, to qualify and quantify sustainability issues relating buildings and environments, and analyzing evolution over time.

For example, The Las Flores Lodge (Figure 1), a representative example of the architecture of the first pioneers in the region. Is analized with the Environmentally Responsible Design Methodology (Table 2 and 3).

ADAPTA-BILITY	WATER	ENERGY	MATERIALITY	ACCESIBILITY	NATURALLY TY	EMISSIVITY	CAPACITY	OPERATIVITY	RACIONALITY
	Care and efficiency	Care and efficiency	and enclosoures	universal in design	conditioning, lighting and ventilation	GHG emissions	with the equipment	in the efficient use	in construction processes
10 0	7 3	3 7	8 2	0 10	6 4	3 7	4 6	2 8	7 3

Table 2 - Values Environmentally Responsible Design Methodology
Lodge Las Flores

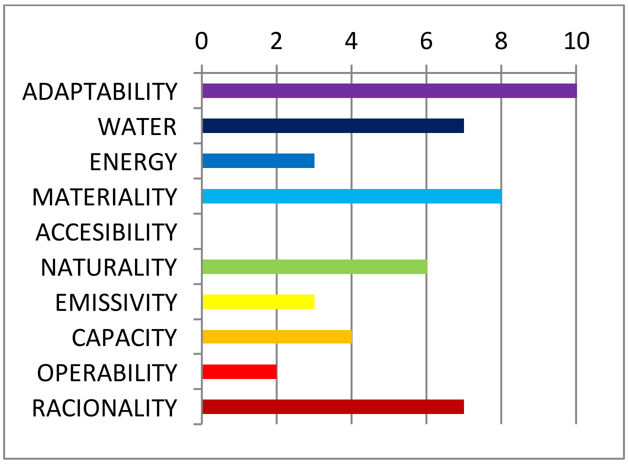

Table 3. Values of Environmentally Responsible Design Methodoloy for the Lodge Las Flores, Nahuel Huapi National Park.

Figure 1. Lodge las Flores, Nahuel Huapi National Park

Other example is the Building of the Park Headquarters (Figure 2) of the National Park (1936). Through the new architecture of National Parks was looked for a mountain image with strong central European influences, defined by the formal and the use of stone and wood. Often listed as picturesque, they have provided local features and regional character to the image of the National Parks Administration. Is analized with the Environmentally Responsible Design Methodology (Table 4 and 5).

ADAPTA-BILITY	WATER	ENERGY	MATERIALITY	ACCESIBILITY	NATURALLYTY	EMISSIVITY	CAPACITY	OPERATIVITY	RACIONALITY
	Care and efficiency	Care and efficiency	and enclosoures	universal in design	conditioning, lighting and ventilation	GHG emissions	with the equipment	in the efficient use	in construction processes
7 3	1 9	1 9	6 4	3 7	5 5	0 10	2 8	2 8	2 8

Table 4 - Values Environmentally Responsible Design Methodology

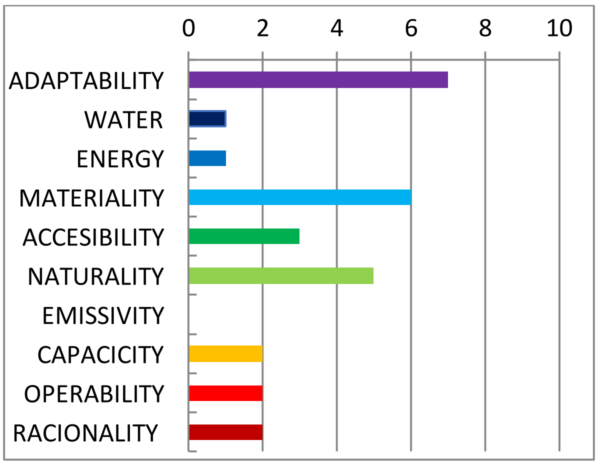

Table 5. Values of Environmentally Responsible Design Methodoloy for the Headquarters, Nahual Huapi National Park.

Figure 2. Headquarters Nahuel Huapi National Park

Conclusions

This paper emphasises the importance of incorporating innovative approaches to promote the protection of natural environments, providing effective enforcement measures within the development of built environments located in sensitive natural hábitats. This methodology allows incorporating effective measures to achieve designs that impact responsibly on the environment. From its application through the detailed analysis of buildings, a percentage value will emerge, because there are ten attributes with ten items each. The points Naturality and Materiality include the analysis and assessment of authenticity, the use of traditional constructive traditions and their materials.

As an original contribution to this context, the paper proposes bases to establish sustainable construction requirements in environmentally sensitive sites, prioritizing the design capacity and feasibility of potential implementation within the institutional framework of the National Park Administration, providing configurations and actions for the construction Of environmentally responsible project-architectonic narrative in extremely sensitive natural environments. This promotes the development of new designs with strategies that minimize the impact of construction, to enhance the heritage of natural and cultural heritage for current and future generations.

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Design to Thrive

The wealth of a house lives in its empty space. Vacuum appropriation strategies between traditions, innovation, flexibility and use

Simone Solinas[1]

[1] University of Cagliari, Dipartimento di Ingegneria Civile Ambientale e Architettura, Cagliari, Italy, Via P.ssa Maria 74, 07100 Sassari, Italy.

Abstract: The quality of the vacuum-space is a parameter of sustainability understood as potential adaptability of a project to its interpretations and modifications implemented over time by users. The appropriation of vacuum is an architectural design strategy which aims to enclose a formless void portion. Vacuum finds its most immediate representation in Nature and, placed in relation to the full, reach a balance in the final built system. 26 social houses built near Seville develop sustainability research through the vacuum-space, reinterpreting local typology consisting of deep courts, modulated by patios sequences that alternate solids and voids, lights and shadows. Weaving the full-space with the empty one, suggesting a close relationship between interior-exterior, it is possible to get a flexible spatial mesh susceptible to modification, studied as unit's expansion program, according to the needs that may arise in time by users. Sustainable housing quality is guaranteed by cross ventilation and intensity lighting controlled by the openings membranes, covering elements, vegetation, that contribute to energy efficiency and degrees of privacy between the different constituent parts of the house, and these and the relationship with the public space of the street.
Keywords: space, void, patio, tradition, flexibility.

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Introduction

“Surely the architect possesses thoughts and interests, passions on the patio and the void. These ideas have certainly engraved in the design and implementation of its houses next to the River. Perhaps he thought, while building them, that he would like to live there. As he could not occupy all, or at least not all together, it was clear that other people would lived in those houses. Someone now is living there and perhaps also the architect. We do not know whether they live in his own way, or in their own way. Curiously we can ask us.” (Unknown, 0000)

Determine which are the parameters to be used to build and analyze a work is not easy. The quality of a project, out of certain types of prejudice especially in social housing, is a first theme complex and intriguing. The quality of a project is achieved by offering users spaces that can be adapted and modified according to their diversity. Environments included in a context of continuity with the past, which look to the future recognizing the importance of sustainability in design that opens to a broad concept of this term, which includes the use of ecological materials and energy-saving, but it goes further.

A second theme, the "use" of space, especially in its component vacuum-space, acquires an extreme importance to reach the main goals that the architecture is proposed. Void-space and full-space should not necessarily be read in an apparent contrast between spatial and geometric mass. The opposition of the two terms should be seen, rather than in a abolition of the two parts, as a dialectical relationship between these extremes. Their relationship is essential and necessary in the construction of space, constituting the two fundamental elements that enhance the meaning.

The homes of the case study are like tubes placed on the table in a scientific laboratory. A brief description, let's say objective, of the project highlights some key aspects and some reflections that will be discussed in this essay: the continuity of contemporary project with tradition and history; the relationship with sustainability understood as energy savings essentially based on passive systems that affect the shape of space; the flexibility of use in the post-built.

Case study

The 26 social houses built in Umbrete near Seville develop sustainability research through the vacuum-space reinterpreting the local typology consisting of deep courts that penetrate in the block, modulated by patios sequences that alternate solids and voids, lights and shadows.

Figure 1. View of the intervention.

The project strategy chosen is the internal porosity which is opposed to the apparent compact exterior of the block, model that interprets the local ways of life that "occupy" the spaces of the road as much as those of the house. The project therefore aims to define at the same time some key issues: on one side the house type, and on the other the global image of the intervention, as well as the relationship of both with the urban context.

The first strategic and conceptual act resolves the project by occupying the entire surface available of the block, without leaving to chance any residual space, with an alternation of volumes, solids and voids, which establish a close relationship between them, thus drawing the entire project.

A first reading of the principal elevation provides a compact image, almost two-dimensional, with the presence of measured windows on the first floor and large openings on the ground floor, veiled with a wire mesh that protects from the gaze of passers.

The overall image gives form to a project where the outside just shows slightly the different cells of which it consists, and proposes a vision of unity and global image, establishing a dialogue with the urban fabric, and coexisting harmoniously with the examples of traditional domestic architecture. Inside the house a succession of full and empty volumes occurs. Spaces that are at the same time internal and external, that are surrounded and in turn surrounded, allowing to play with the lights and shadows that glide on the walls.

The access to each house, from the street, is produced under a covered space which can be used as a car park, open to the street on one side, and on a first patio on the other. This first sequence between "full and empty" generates the threshold between public and private which continues, within the home, with the living room. The sequence is completed by a second patio, intimate and hidden -the lemon patio, which overlooks the kitchen. In the interior, the stair climbs up in a double-height volume joining the two floors vertically, bringing on a catwalk that connects horizontally the bedrooms and a terrace-solarium, located above the living room. The "voids" of the house, internal or external, are essential in the overall reading of the project, along with the "full" generate the living spaces of the house itself.

The intervention proposed is therefore a route between full and empty spaces that alternate constantly at various levels, both in a longitudinal as well as in the transversal reading, creating a sequence of rooms and environments some of which open to the sky. This is a reinterpretation of the succession of spaces typical of the Andalusian Baroque patio house, hybridization itself from the Arabic and Roman typology.

Continuity and tradition

The comparison of a typical house of Seville and those in analysis highlights some features of similarity that concern two aspects: the elementary pieces that make up the project and their concatenation and composition.

Figure 2. Plan of a typical patio house in Seville (left) compared with case study (right).

The spatial sequence between entrance hall, first patio, living room and second patio/garden is evident in the two examples exposed (the historical and the contemporary one) regardless of scale issues or building systems used. This sequence is found in numerous examples of contemporary architecture and it opens to multiple reflections which can only be mentioned in this brief essay.

This alternation of light and shadow, of indoor and outdoor spaces, covered or open, it is also verifiable in the association between the sketch of Le Corbusier, realized during the journey to Pompeii in 1911, and the internal perspective of the Villa Savoye of 1929. It is possible to argue and support that will ultimately be (in all 3 projects) the same spatiality, or classical spatial configuration, composed by *fauces*, *atrium*, *tablinium* and *peristylium*. The description given of the phenomenological experience in Towards an architecture of the House of the Silver Wedding by LC it is perfectly transferable to the Villa Savoye.

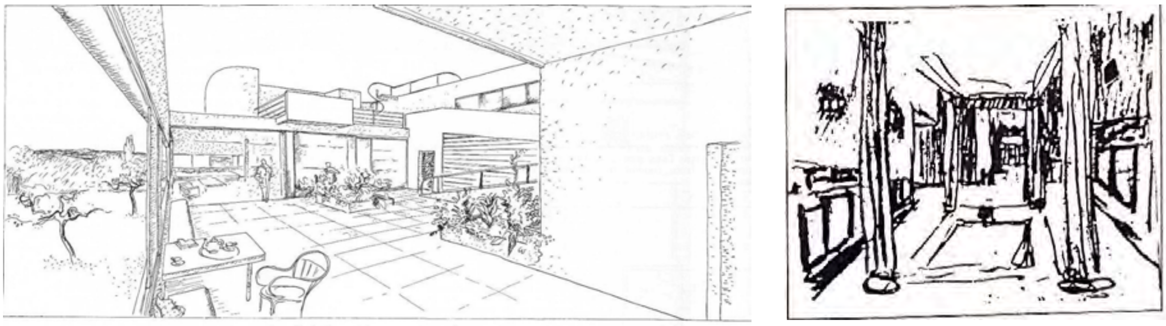

Figure 3. Drawings of Le Corbusier: Villa Savoye and Pompeii house of Nozze d'Argento.

The sequence of elementary components of the Pompeii's houses can be found in the structural organization of the houses in Umbrete.

Figure 4. Sequence of penetration following *fauces, atrium, tablinium and peristilium* composition

Not only this; it is possible to document that, as proposed by Richard Padovan, "the Villa Savoy in Poissy is a courtyard inside a pavilion" (Padovan, 1995). This aspect is even clearer if we associate and visualize the spatial sequence of the elements of the Villa in Poissy plan with the plan of the House of the Silver Wedding near Naples. This aspect highlights the importance of the sequence of empty spaces particularly in the use of the "patio as an archetype polyvalent, able to collect beneath itself a large amount of uses, shapes, sizes, styles and different characteristics" (Capitel, 2005)

Sustainability aspects

Starting from the data of the project program and a careful analysis of the context, introducing sustainability data as necessary elements but in itself not sufficient (materials, longevity, energy balance, passive environmental use of energy, natural lighting, natural ventilation, orientation, volume, etc), you will get the best possible welfare housing conditions, reducing consumption and waste. Architecture is a great amalgam of elements that must work together (space, structure, systems, economy, active systems, passive, etc.) in a global constructive act, not to mention an aesthetic and formal richness, which is critical in our work.

The main effort in Umbrete design was directed to a passive energy operation of buildings, whereas the cost of the construction of only 526.22 euro/m2 and a selling price of 68,355 euro for each house (year 2007), has made impossible to install systems with active technologies. The simple construction and the use of readily available materials and known by local workers have been the dominant choices: large thermal mass in the thick audience of foundations, walls and vaulted roofs, allow us to isolate ourselves from the heat in summer and cold in winter.

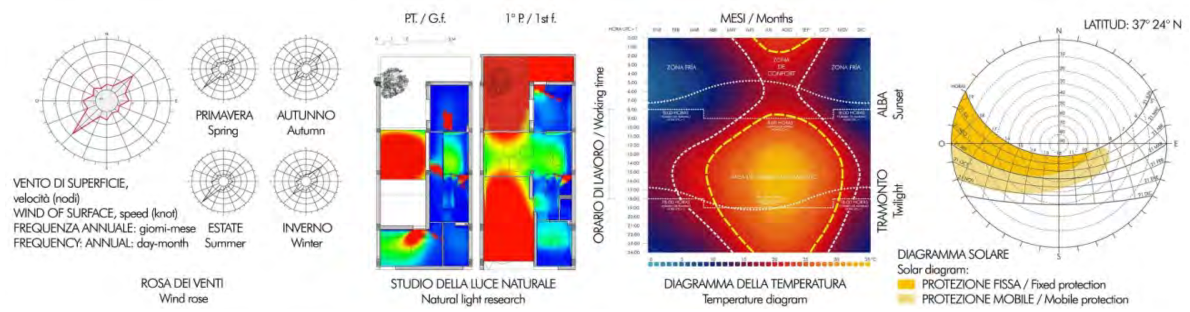

Figure 5. Sustainable scheme.

The proposal distribution in the block was a result of the conditioning initially perceived as negative, such as solar orientation, which had the longest prospects on the northern and southern facade. This imposition has led to the search of the proposed solution, which is considered climatically optimal. The living rooms and master bedrooms, assigned on either side of the lot, but symmetrically distributed, have been designed to always have views simultaneously on both exposures.

The sustainable housing quality is also guaranteed by cross ventilation and intensity lighting controlled by the openings membranes, covering elements, vegetation, leaving the possibility to the sun to penetrate when appropriate, taking advantage of the seasonal variation of its angle of incidence on the ground. These are key issues in the climate of southern Spain, that contribute to energy efficiency and a good degrees of privacy between the different constituent parts of the house, and also between these and the relationship with the public space of the street.

Flexibility

Each interior space is linked to its own external reference space that is studied as the unit's expansion program.

The minimum surface of 70m2 useful provided by the Andalusian legislation, distributed in three bedrooms, living room, kitchen, bathroom and circulation have been designed as "hopefully modifiable” or extensible by some suggestions/consideration proposed in the design phase, to improve the user adaptability to the project. The house would not change its essence and nor its relationship and its overall look with the outdoor spaces of the road, if you extend the kitchen to the garden at the end of the lot. (Figure 6. Option b). This would result in more room to eat and keeping the close relationship with the open space of the lemon patio.

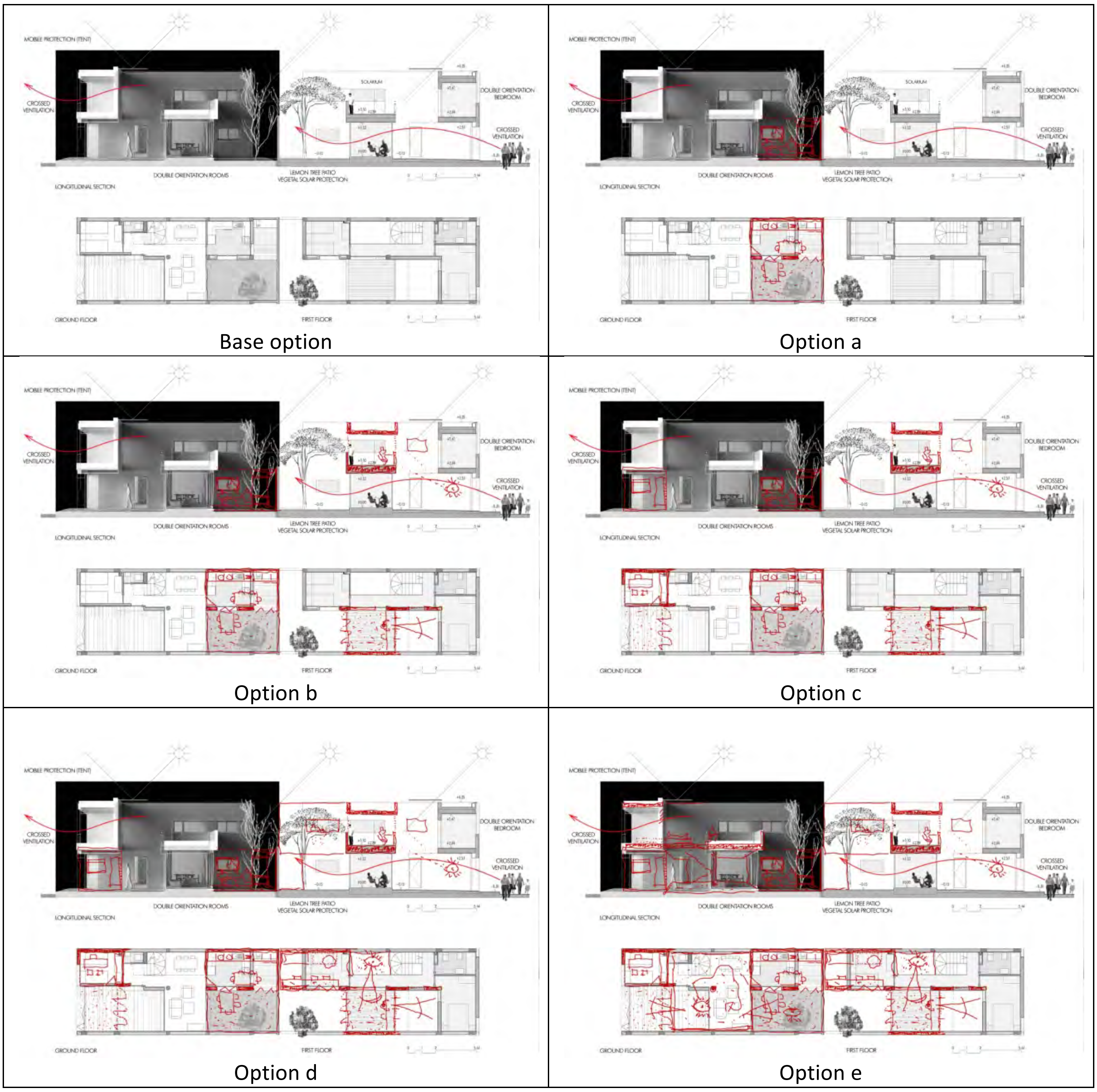

Figure 6. Scheme of extension and modification of the base plan. Flexibility.

Upstairs, the room in the kitchen correspondence has been studied for a possible extension (Figure 6. Option e.). Also on the first floor, you could build an additional room in the solarium, with the simple addition of a roof between the existing walls, thus creating a new bedroom. This would be useful in the case of the arrival of a new family member, giving also the possibility of an extra space for a study area, maintaining, without substantial changes the sequence of the patios existing in the original project (Figure 6. Option c). The room on the ground floor, which is the only enclosed space in direct contact with the outside, can be made independent from the rest of the house, to respond to the changes required by the job, and open directly onto the adjacent access space (Figure 6. Option d). The latter could also be close and attached to the "inner" part of the house. Possibilities that may be needed to accommodate a ever-changing society.

Conclusion

In designing new works it seems to be important the relationship with the past. It is clear that our physical position in time and space can only be the one that occupies the present. It remains significant however the way we look at the past -depending on the problems that we have in the present- and how we use it to generate future solutions. Many are the possible pasts. We can observe them with the eyes of the Angelus Novus, a painting of Paul Klee, without being able to know the future towards which we travel.

The picture has long been owned by Walter Benjamin who has developed a complex philosophical point of view about history and its relationship with the present and the idea of progress. At the same time we must realize that every time we design we are going to take a leap into the void. We do not know exactly what we will find. This launch is yet to be done.

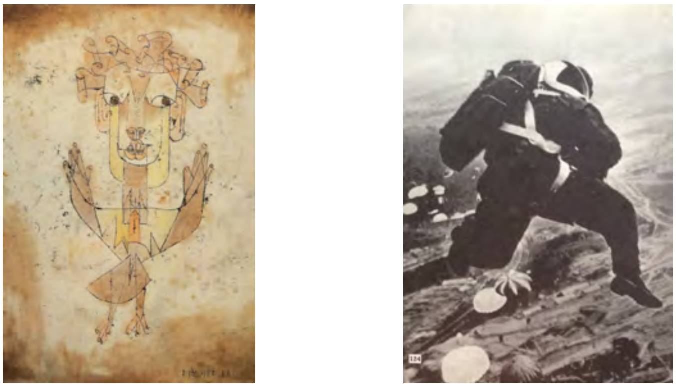

Figure 7. Paul Klee, Angelus Novus. Le Corbusier, Aircraft.

This jump is not simply about and towards the construction of new buildings, but also involves an analysis of our works once constructed and used, after a prudential time period defined as post-built, in which users have taken possession of the designed spaces.

If the work just completed and built can tell some of his stories, the work inhabited reveals its true essence and its potentials. The following images tell us a fraction of this reflection.

The first picture was done by an architectural photographer. It shows the purity of forms, the depth of space, and the electrical blue of the sky. The second one is a lucky camera shot, from the same spatial point of the other picture but with coloured human figures that are moving, playing and living in the penumbra of the inner space. Same space, different space!

Figure 8. Same point, different space.

10 years after the construction of the 26 social houses in Umbrete is carried out an analysis that "detect" and “reveal” the changes introduced by the use of housing units to find the matching of the adaptability assumed in the project, as if it were an experiment in test tubes, in order to detect whether exist or not the adaptability and flexibility think time ago. It is necessary to consider about the past/present through the views of users involved building a new sustainable quality.

Figure 8. Inhabitants.

The observations that arise from the process of post-built verification, lead to further reflections on how collocate ourselves in front of next projects, giving a deeper meaning to this profession. Reflecting on the past, to dream another future.

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Statistical and Spatial Analysis of Climate Data for Updating Passive Design Strategies in Brazil

Iraci Stensjö[1] and Camila Ferreira[2]

[1] Environmental Comfort Lab, School of Architecture, Federal University of Minas Gerais, Belo Horizonte, Brazil, iracistensjo@gmail.com;
[2] Environmental Comfort Lab, School of Architecture, Federal University of Minas Gerais, Belo Horizonte, Brazil, camilaccferreira@yahoo.com.br;

Abstract: In Brazil, the standards for thermal performance of buildings, and the certifications to evaluate building energy efficiency are based on thermal comfort indexes, whose recommendations are obtained from climatic data of the Climatological Normals of the period 1961-1990. Between 1990 until today, the country underwent major transformations in its territory, such as the reduction of forest area, advancement of the agricultural area, expansion and densification of urban centres. All these factors may have affected the macro, meso and microclimate. Thus, data for the period 1961-90 may not reflect the current climate and the condition of acclimatization of populations. The purpose of this research is to analyse the most current climatic data, aiming to assess whether or not there are changes in the climate that affect comfort, as well as verify the pertinence of the current recommendations for thermal performance. The selected data for analysis are air temperature and humidity for the period 1985-2015, provided by the National Institute of Meteorology. The methodology uses descriptive statistics to determine the trends and variability for behavioural assessment of climate change. Subsequently, building design strategies of different comfort indexes, such as Givoni, Mahoney are revised regarding the new climate data, as well as, the changes in neutral temperature and degree-days. Then, spatial distribution of the results is present in thematic maps, thus one can assess the regional trends inside Brazilian areas. As a result, the mean temperature of cities had increased all over Brazil, which causes changes in the recommendations for thermal performance

Keywords: climatic data, climate changes, thermal comfort, adaptive comfort, project strategies

Introduction

The indices of human thermal comfort are widely used in Brazil for evaluation of thermal comfort and building energy efficiency. Frequently, they are used to analyse the climatic characteristics of a given location from the viewpoint of human comfort and specify building design guidelines to maximize the comfort conditions for passive buildings, the most common type of building in Brazil. For these reasons, the indices are used in the definition of parameters of performance and comfort of different Brazilian norms and regulations, such as (ABNT, 2005), (ABNT, 2008), (INMETRO, 2010), (INMETRO, 2012).

These documents were developed using the Climatological Normals of 1961-1990 (Ramos, et al., 2009) as database for climate analysis, since it is one last Normals published in Brazil. Between 1990 until today, the country underwent major transformations in its territory, such as the reduction of forest area, advancement of the agricultural area, expansion and densification of urban centres. All these factors may have affected the macro, meso and microclimate. Thus, data for the period 1961-90 may not reflect the current climate and the condition of acclimatization of populations.

This work evaluates two climatic databases with different temporal cut-offs, for the Brazilian territory, to verify local climate changes, and to assess if the changes impact on the building design strategies. The climatic databases chosen are the Climatological Normals of 1961-1990 (Ramos, et al., 2009), and digital data from 1983-2013 retrieved from the Brazilian Institute of Meteorology website (INMET, 2016). They were chosen because they have a large number of stations and because their data are collected with the methodological rigor established by the WMO. In addition, the time range between the bases allows to study if the urban transformations that the country has undergone have affected the local climate in some way.

The analysis of the comfort conditions uses the adaptive model proposed by Dear and Brager (2002) as an alternative to the method of ASHRAE Standard 55 of 1998. In addition, the study of the changes in design strategies is carried out by the Mahoney's Tables (United Nations, 1971) and the Building Bioclimatic Chart (Givoni, 1992), because they are simple methods of climate analysis that incorporate comfort indexes, they are widely used in Brazil, and they provide guidelines in early stages of the architectural design.

The database

In this work, the data of the Climatological Normals (Ramos et al., 2009) are used as the reference, which correspond to the monthly averages from January 1961 to December 1990. Specifically, sine curve of temperature and humidity data to evaluate human thermal comfort, because this is also the method used in the norms to define Brazilian bioclimatic zoning. Since there is not another Normals series published after, raw data was downloaded from the national digital database (INMET, 2016), then the arithmetic average calculated. The selected period is 1983-2013, 20 years of data, because there are just a few cities with 30 years of data. The variables retrieved are: mean monthly hourly temperature, T; mean monthly maximum temperature, T_x; Mean monthly minimum temperature, T_n ; Atmospheric pressure at the barometer level, P (in Pa); and, mean relative humidity, RH (%)

The definition of a typical day

The database provides average values that may not be representative of the comfort conditions. So, hourly values for typical days are calculated. The average hourly air temperature data can be obtained by adjusting the local data to sine curve of the World Meteorological Organization (WMO) (Assis, 2001), as described in Equation 1:

$$T = T_{\mathrm{x}} - (T_{\mathrm{x}} - T_{\mathrm{n}}) \cdot j \qquad 1$$

where

j is the setting value of the hourly temperature curve, from 0 h a.m. to 11 h p.m.: 0,75; 0,78; 0,82; 0,87; 0,89; 0,96; 1,00; 0,93; 0,76; 0,57; 0,41; 0,28; 0,15; 0,11; 0,02; 0,00; 0,04; 0,08; 0,15; 0,46; 0,56; 0,64; 0,73; 0,70.

The daily range of relative air humidity is estimated according to the Brazilian Standard NBR 15.220 (ABNT, 2005). This standard presumes the average daily variation of absolute air humidity equal to 3 grams of water vapor per kilogram of dry air. The hourly value of the humidity was determined from the hourly vapor pressure as a function of the air temperature.

Thermal comfort models

The adaptive comfort temperature

Adaptive comfort models are based on fieldwork that measures the environmental conditions and the simultaneous response of thermal sensation of individuals involved in their usual tasks, with the least possible intervention of the researchers, in an attempt to reproduce the real conditions. This work uses the model presented by Dear and Brager (2002), which is the model used in the review of ASHRAE 55 in 2004 and it is widely used in Brazil. This regression model calculates the optimal comfort temperature, T_{conf}, based on the external climatic conditions, characterized in terms of mean outdoor air temperature (T) (Equation 4) (Dear & Brager, 2002, p. 553). They also define zones of comfort: for acceptability of 90% the range is 5 °C, and for 80%, 7 °C, both zones are centred on the optimal temperature of comfort.

$$T_{conf} = 0{,}31 \cdot \mathrm{T} + 17{,}8 \qquad (4)$$

Mahoney Tables

Carl Mahoney, John M. Evans and Otto Königsberger. (United Nations, 1971) elaborated a series of Tables that offer recommendations to the architectural project from the analysis of climatic data, useful in the initial stages of the project. The thermal comfort zones proposed in the tables vary according to the annual mean monthly temperature, period of the day (daytime or night-time) and monthly average relative humidity. The Mahoney Tables are often used in bioclimatic design in tropical climates, so it is considered unnecessary to reproduce all of its methodology in this text.

Building Bioclimatic Chart

The Building Bioclimatic Chart (BBCC) was developed by Givoni (1976) and it was later expanded by Milne and Givoni (1979). It is a method of graphical climate data analysis, as well as, building design guidelines, especially for hot climates. The chart of human thermal comfort zone is drawn in a psychrometric chart. The BBCC differs from others comfort charts because it presents partial charts of the climatic conditions within which various building design strategies and natural cooling systems can provide indoor comfort.

Statistical treatment of climatic data

The behavior of T, T_n and T_x data, in both database, is evaluated by data dispersion plots as well as linear regression models. A linear regression model is given by Equation 5, where β_0 represents the intercept of the trend line with the y-axis and β_1 the slope of the line. The value of β_1 will indicate whether there is a tendency for temperature values to increase or decrease.

$$y = \beta_0 + \beta_1 x \qquad (5)$$

The linear regression models allow evaluating the slope of the trend line, which indicates whether there is an increase or decrease in the value of air temperatures in the data 1983-2013 compared to the 1961-1990 data. In addition, the standard deviation values between the databases are calculated for T, T_n and T_x. The standard deviation (s) is given by Equation 6, it measures the dispersion of the individual (y_i) values around the arithmetic mean ($\bar{y}$), where n is the number of observations.

$$s = \sqrt{\frac{\sum(y_i - \bar{y})^2}{n-1}} \qquad (6)$$

Results

The results of this work are presented in two modes: graphs and maps. The graphs present the statistical trend of minimum, average and maximum temperature data. The maps present the data spatially distributed, allowing the spatial comparison between the two databases adopted. The maps of population are also presented, in order to identify possible relations of growth of the cities and the identified climatic changes.

Statistical trend of the data

The scatter plots for T_n (in blue), T (in green) and T_x (in orange) of both databases are presented in Figure 1, as well as linear regression models. They indicate the increase of the three temperatures in 1983-2013 compared to 1961-1990 database. The standard deviation also shows the trend of increasing temperatures in the most recent data. However, the standard deviation calculated for the T_n (5.8 °C) is higher than T (1.7 °C) and T_x (2.7 °C). Thus, it can be concluded that the increase of T_n is more significant than the general increase in temperature.

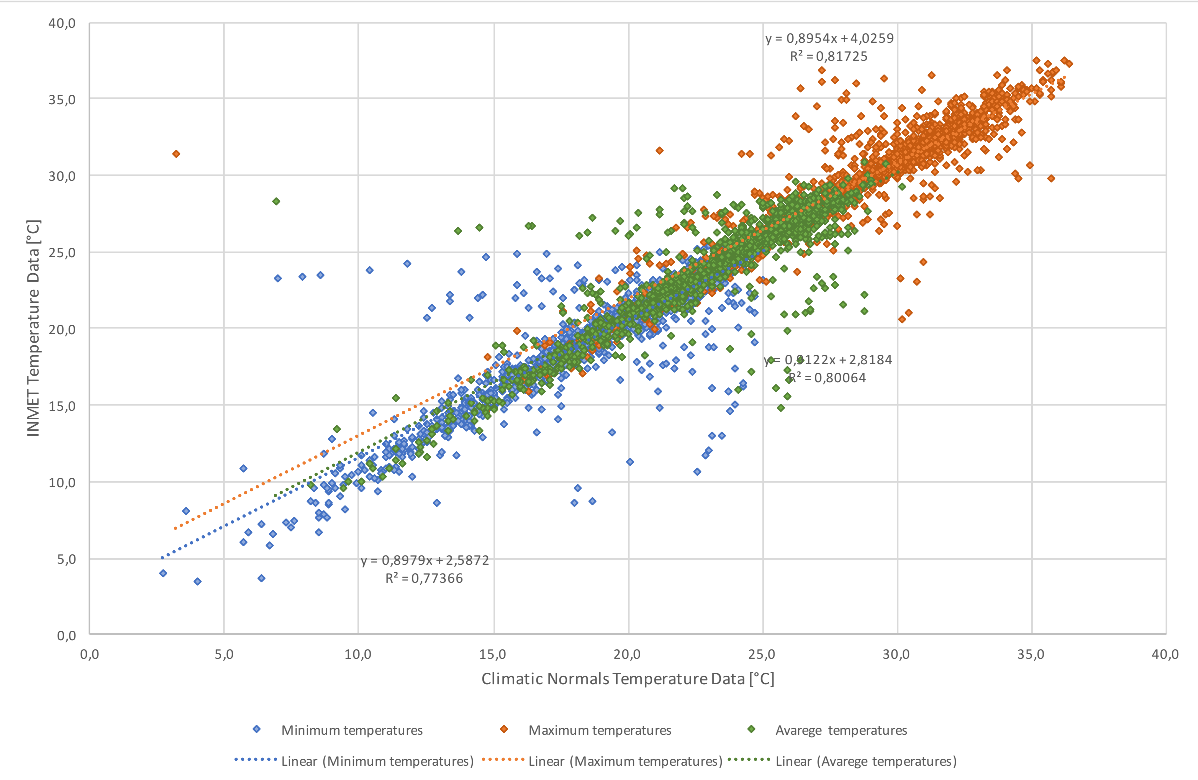

Figure 1. Scatter plots for T_n (blue), T (green) and T_x (orange)

Maps

Weather stations are not always the same in databases. Many were disabled, several were created. In addition, the 2013-1993 database does not contain stations that are still analogic, so there are fewer stations. Thus, the spatial analysis is relevant because maps allow to evaluate the trends by region, by comparing nearby stations, even if they are not exactly the same.

The first set of maps presents the population changes. Figure 2 compare the population of municipalities where the weather stations are, in 1992[1] and in 2012. The maps are divides by administrative regions: North, Northeast, West, Southeast and South. In the last 50 years, there was a demographic explosion in Brazil and the country had an increase of approximately 130 million people. But this growth occurred mainly in the capitals and their metropolitan areas. The Southeastern region received the largest migratory flow in Brazil, during the period of study. It is the region with the greatest growth in the number of large towns and cities (yellow and orange dots in Figure 2), besides contemplate the 3 largest Brazilian metropolises.

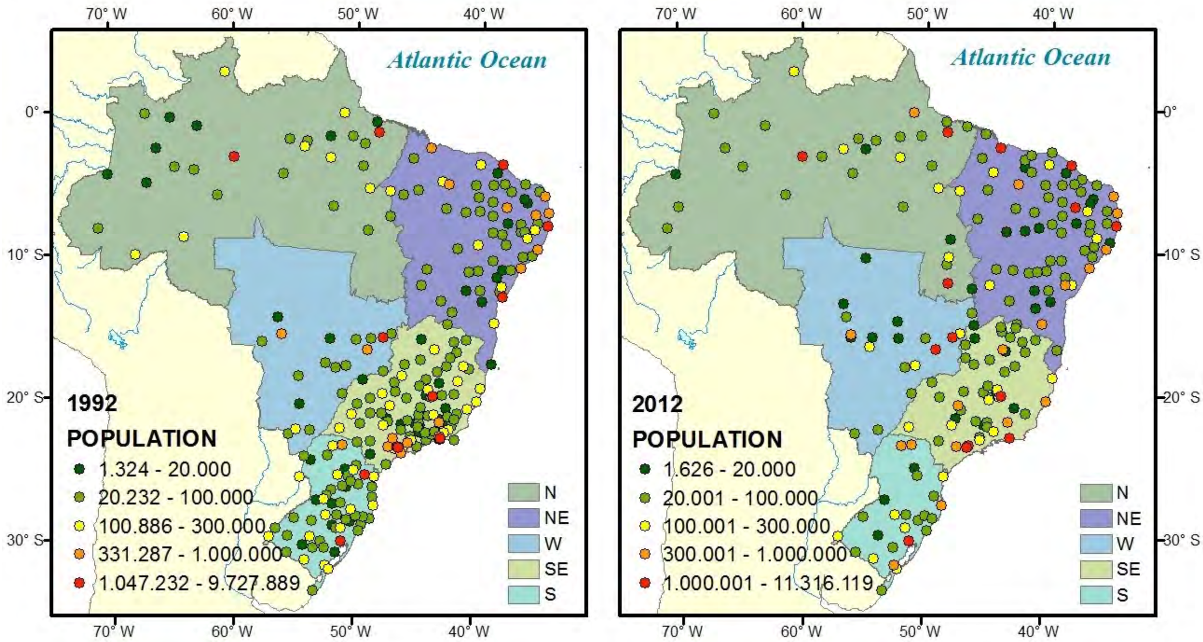

Figure 2. Population of municipalities

The second map (Figure 3) represents the percentage of hours of thermal comfort, considering the Bioclimatic Chart developed by Givoni (1992). There are almost no changes in North. In Northeast, the number of hours in comfort is reduced (~10%) in the stations near coast. There are fewer stations in the South and Southeast, but there seems to be a reduction in comfort hours of about 10% in some stations. The increase of discomfort is higher in West (20%) and more frequent.

Figure 4 shows the comfort hours using the adaptive model of (Dear & Brager, 2002) and a range of temperatures around the comfort temperature of 3,5 °C, corresponding with 80% thermal acceptability. In 2013, there is a common increase of comfort hours of 10% in the North Region, but comparing the numerical values, there was a reduction of 2% in the average number of hours of comfort. The same trend happens in some stations of the NE, particularly those near the north coast. On average, there is a reduction in the number of hours in comfort of 4% in NE. In the West Region, there seems to be no significant change in the maps, but the average number of comfort hours has reduced 7%. However, the hours of comfort are reduced in some stations inside the SE Region. This is the region of the greatest reduction in average hours in comfort, 9%. In South, the comfort hours have increased in many stations. In average, considering all stations in S, them have reduced 1%.

[1] 1992 is the first year of digital data available for all Brazilian cities in the Brazilian Institute of Geography and Statistics (IBGE, 2015).

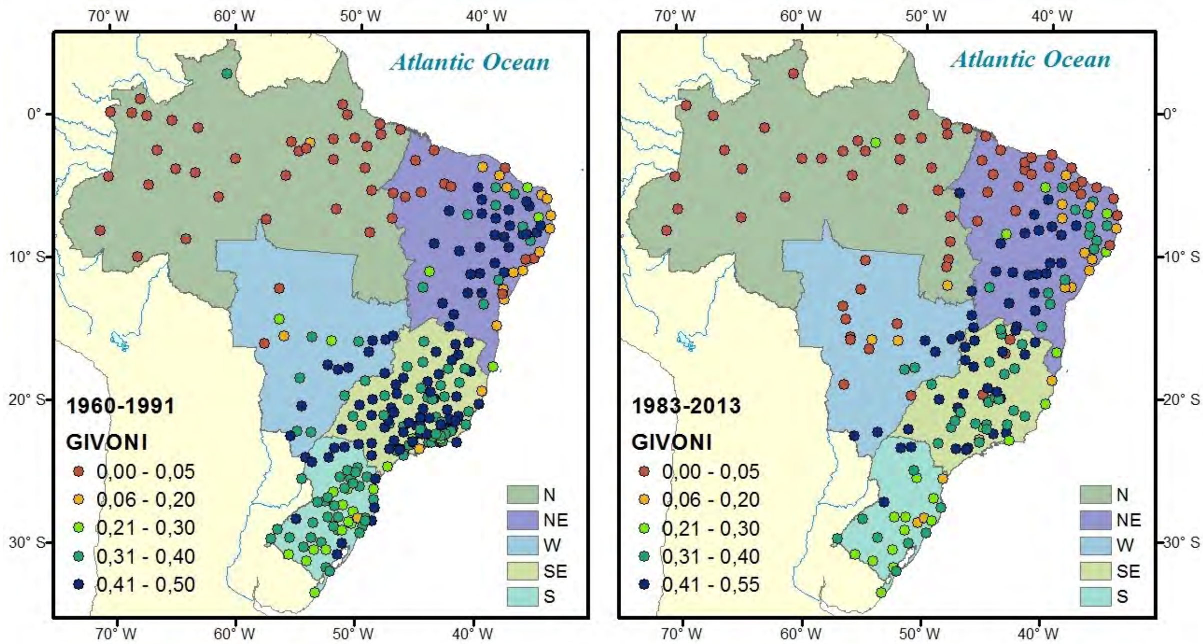

Figure 3. Comfort hours in the year (%) according to Givoni's bioclimatic diagram (Givoni, 1992)

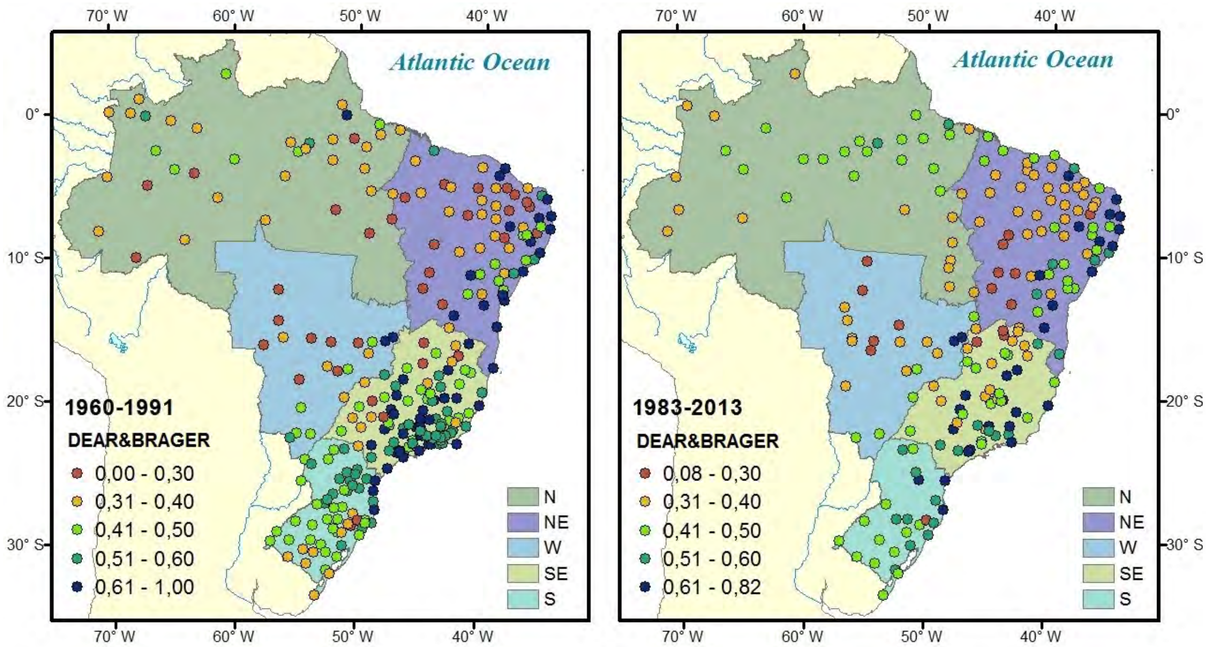

Figure 4. Comfort hours in the year (%) according to Dear and Brager (2002) (80% acceptability)

Comparing Figure 2 with Figure 4, one can see that the cities with the greatest changes in the hours of comfort were the big cities, pointing out that there is a relation between the population growth and the increase of the discomfort due to the increase of the temperature.

In all regions, there is a reduction of comfort hours regarding Givoni and the adaptive model. The next maps show the Mahoney indicators, so we can evaluate the impacts of the changes of the humidity. H1 is applied when high temperature and humidity are combined or high temperature, moderate humidity and small diurnal range. The arid indicator A1 is applied in months when a large diurnal range coincides with moderate or low humidity. Figure 5 shows the maps of H1 indicator, and Figure 6, the maps of A1. The only region with significant changes is the Southeast, where there is a reduction of the number of months in H1 and the increase of A1 in several places.

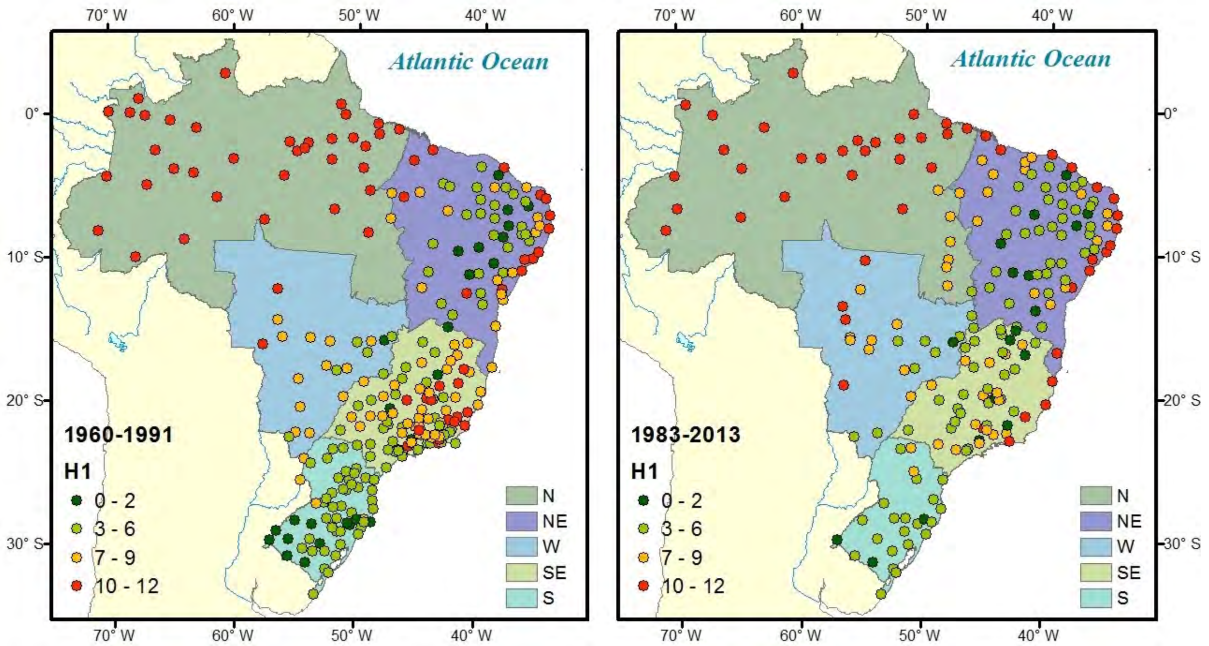

Figure 5. Total of humid indicators H1 per year, according to the Mahoney Tables. (United Nations, 1971)

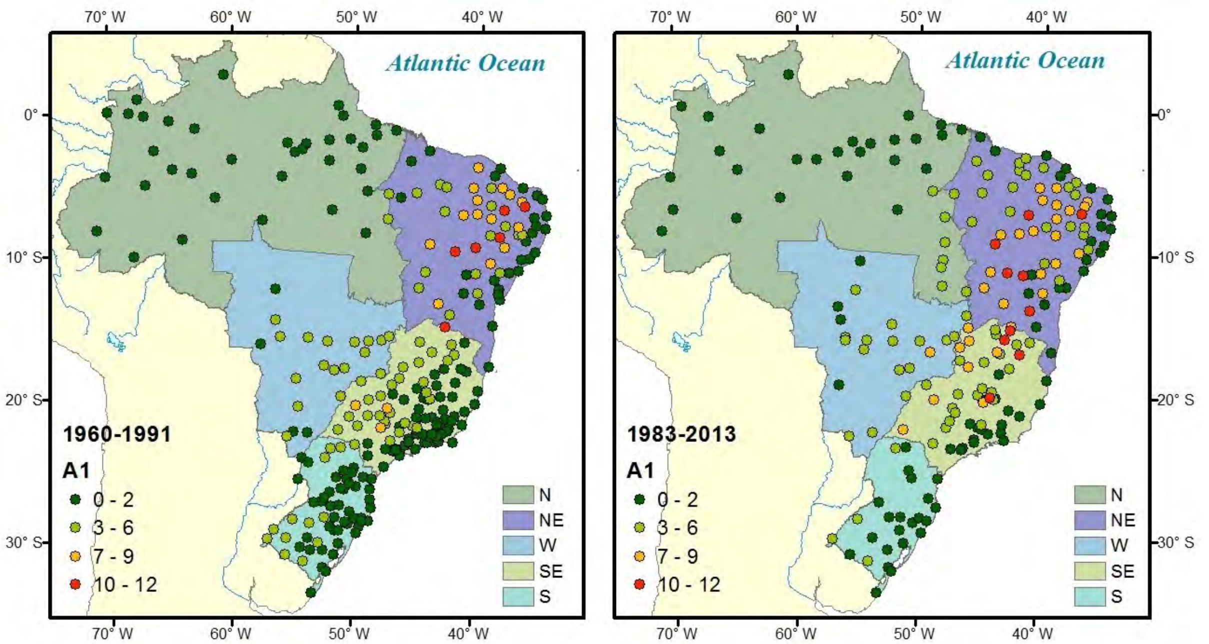

Figure 6. Total of arid indicators A1 per year, according to the Mahoney Tables. (United Nations, 1971)

Final Comments and conclusions

The indices of human thermal comfort are widely used in Brazil for different functions, however there is no standard in the country that establishes comfort conditions according to acclimatization of the Brazilian population. Thus, the present work proposed to perform a more updated climate data analysis to evaluate the changes in the human comfort response, as well as, to verify the relevance of the current design recommendations for building thermal performance.

The results show an increase in the minimum, average and maximum temperatures, which causes a reduction of comfort hours regarding the adaptive model, in all regions. The stations that experienced the greatest reductions in comfort are in North and Northeast regions, the hottest climates in Brazil. The South Region has the least change in comfort hours, because the increase in temperature resulted more hours of comfort in some cities of cold climate.

The Southeast Region experienced the highest reduction in the sensation of comfort considering the adaptive model; and considering the Givoni model, the Western Region. The Southeast Region also has become drier and has less problems of cold, according to Mahoney. These climatic changes are probably due to the growth of cities in this region, both metropolises and intermediate-sized cities.

In general, it can be noticed that there have been changes in comfort and recommendations caused by the elevation of temperature. Therefore, the growth of cities appears to be an active factor, but not the only one, demonstrating the need for further studies.

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Optimization of Fenestration Design in Cold Climate Regions Based on Photothermal Performance

Yixin Tian[1], Qiong Huang [1], Jingyuan Zhao [2]

[1] school of architecture, Tianjin University, Tianjin, China, No.92 Weijin Road, Nankai District, 383696605@qq.com
[2] school of architecture, Chang'an University, Xi'an, China, Middle of Nanerhuan Road, Beilin District

Abstract: The external envelope of a building has a significant effect on its energy consumption. Windows are a weak component of the outer envelope. Appropriate window design can take advantage of solar radiation and daylighting to improve a building's thermal performance. In this paper, the characteristics of windows (orientation and window-wall ratio) and office building geometry are investigated to study the energy consumption characteristics of individual office rooms. DAYSIM and DesignBuilder software are used to simulate the energy consumption and daylighting performance of offices in the city of Xi'an, located in a cold climate region in China. We analyse the relationship between spatial office parameters and energy consumption and the relationship between spatial office parameters and the quality of the lighting environment. The evaluation indexes are total annual energy consumption, DAcon and UDI. The results show that as the room index increases, the energy consumption of lighting increases, and the decline of heating and cooling energy consumption gradually slows. When an office is approximately square-shaped, the optimal window orientation is south and 15 degrees west of south, and energy consumption is lowest when the window-wall ratio is 50%-70%.

Keywords: room index, window-wall ratio, energy consumption, useful daylight illuminance

Introduction

Buildings rely on windows for lighting and heat transfer, and the use of daylighting helps to reduce power consumption from lighting devices and to improve indoor environmental quality. However, the absorption of sun radiation through windows introduces heat load and affects the energy consumption of cooling or heating systems, so fenestration design is a critical step in energy-saving design. For multi-storey buildings, heat dissipation through doors and windows accounts for approximately 30% of the building's total heat dissipation. A common method of energy saving using fenestration design is the introduction of appropriate amounts of natural light.

Orientation is known to have a significant impact on building energy consumption. In building energy-saving design standards, it has been noted that building design should select the optimal local orientation or most suitable orientation, and south-facing is the optimal building orientation in Xi'an. "Design Standard for Energy Efficiency of Public Buildings" GB50189-2015 recommends that the orientation of buildings should be south-facing, ranging from 30° west of south to 30° east of south. Different orientations will lead to differences in building performance and energy consumption.

Irina Susorova et al. analysed the total annual energy consumption of office buildings in terms of window-wall ratio, window orientation, and room width/depth ratio. They found that it is most efficient to install south-facing windows in cold regions in the United States; the installation of large windows helps south-facing rooms achieve optimal energy-saving performance, and the installation of small and medium windows is most appropriate for rooms with small depth and large depth, respectively.

Carlos E et al. studied the performance, comfort, and dynamic evaluation of a 3.5m * 5.3m * 2.7m office and applied the chart optimization method to avoid multi-objective conflict and compromised to meet the multi-objective requirements. Ultimately, they obtained optimal window-wall ratios for different orientations and proposed that window optimization is conducive to reducing building energy consumption and providing a higher level of visual comfort.

Steinar Grynning et al. explored window energy balance based on the window thermal performance index (heat transfer coefficient K and solar heat gain coefficient SHGC values). They suggested that even in cold regions where demand for heating is high, office buildings should be designed based on cooling demand. They evaluated the energy saving potential of different combinations of K and SHGC.

Enedir Ghisi et al. simulated rooms using 5 different room ratios and 10 different dimensions in two different regions and used windows to balance daylighting and artificial lighting. They suggested that a large window-wall ratio is most energy-efficient with regard to small rooms and that a low thermal load from solar radiation is conducive to reducing building energy consumption.

Quality of lighting environment and evaluation criteria for energy efficiency

If parameter settings (orientation and window-wall ratio) of windows and office building geometry are different, the indoor lighting environment and energy consumption are different. This paper seeks to determine the optimal window dimensions for offices of different scales to balance energy consumption and daylighting performance.

Energy efficiency indicators include heating, cooling, lighting, and other energy consumption (kWh/m²), and the goal of energy saving is to minimize total energy consumption. China's architectural lighting design standards use static evaluation indicators for lighting environments, such as daylight factor and illumination. This paper uses continuous daylight autonomy (DAcon), useful daylight illuminance (UDI), and other dynamic evaluation indicators of the lighting environment to more accurately and comprehensively study the annual daylighting performance of buildings.

UDI is based on the illumination value on an indoor work surface. This indicator is based on hourly climate data to describe whether indoor daylighting is effective; it is highly accurate and can take into account user comfort. If work surface illumination is less than 100lx, indoor lighting conditions are insufficient; if work surface illumination is greater than 2000lx, indoor lighting conditions are superabundant, and the probability of users experiencing glare greatly increases; the work surface illumination that meets human requirements is 100lx <UDI<2000lx. This range was proposed by Azza Nabil in assessing office space lighting in 2005, and it was confirmed by John Mardaljevic in 2012.

Method

The research content is divided into two parts. The first part examines the influence of office geometry and window-wall ratio on energy consumption and the lighting environment. The second part selects a fixed-size office to analyse its photothermal performance based on its orientation and window-to-wall ratio.

Xi'an (34.3N, 108.93W) is a city representative of a cold region of China. It has a warm, temperate, and semi-humid continental monsoon climate. Its winter monthly average temperature is typically below 0 °C, and its lowest temperature in winter can fall below -16 °C. Its summer monthly average temperature is approximately 26 °C, and its highest temperature reaches 40 °C or above. The climate difference between winter and summer in Xi'an is very large, resulting in high numbers of heating days or air-conditioning days. A north-easterly wind is prevalent throughout the year, annual sunshine hours range between 2,200-3,000, total annual solar radiation is greater than 5,000 MJ/m², and there are characteristics of light and heat over the same period. In using natural light, necessary measures must be adopted to avoid the absorption of excess heat, that is, design must focus on balancing lighting, heating, and sun-shading.

An ideal office model is established. Its roof, floor, and inner wall are built of thermal-insulating materials, and the external wall is constructed following common construction practices in Xi'an, i.e., 20mm-thick cement mortar, 60mm-thick glass wool, 20mm-thick cement mortar, 200mm-thick aerated concrete blocks, and 20mm-thick cement mortar, with a heat transfer coefficient of 0.5 W/m² · K. The g-value， U-value and LT- value of glass is 0.33, 1.4, 0.37.

Heating, ventilation, and air conditioning equipment consist of a fan-coil air conditioning system. Heating uses natural gas as the energy source with an energy efficiency ratio of 0.85. Cooling uses electricity as the energy source with an energy efficiency ratio of 1.19. The indoor temperature is set at 20 °C in winter and 26 °C in summer. Use time is 7am to 6pm, Monday to Friday. The light climate zone of Xi'an belongs to class IV, and the outdoor daylight illumination value is 13,500 lx. According to current building lighting design standards, a 0.75-m-high horizontal plane is chosen as the work surface for lighting; the standard value of lateral daylighting in the office is 500 lx. The windows are double-layer low-E glass. The illumination intensity is 9 W/m², and per capita fresh airflow is 30 m ³/h · people.

Methodology of Part One

The offices mentioned in this article are rectangular and oriented towards the south. The room index (RI) represents the value of the office building geometry, which is calculated as:

$$\mathrm{RI} = 2 \times \mathrm{S}/(\mathrm{h} * \mathrm{l})$$

where S is the room area, l is the room horizontal circumference, and h is the calculated lamp height from the work surface.

For rectangular offices, the expression of RI can be written as:

$$\mathrm{RI} = \mathrm{WD}/(\mathrm{W} + \mathrm{D})\mathrm{h}$$

where W is room width, and D is room depth.

Common values of RI are 0.8, 1, 1.5, 2, and 3; common values of room width/depth ratio (W: D) are 1, 1.5, and 2 (see Table 1). When D: W = 1, W = 2RIh; when D: W = 1.5: 1, W = 2.5/1.5RIh; when D: W = 1: 1.5, D = 2.5/1.5RIh; when D: W= 2: 1, W = 3/2RIh; and when D: W = 1: 2, D = 3/2RIh(see table 1). The height of the room is 3.6 m, the height of the office work surface is 0.75 m, and the height of the lamp from the work surface is 2.85 m. The windows are located in the centre of the external walls, with window-wall ratios varying from 20% to 80%, in increments of 10%.

Table 1. Room index and room dimensions

RI	2 : 1		1.5:1		1:1		1:1.5		1:2	
	W	D	W	D	W	D	W	D	W	D
0.8	6.8m	3.4 m	5.7 m	3.8 m	4.6 m	4.6 m	3.8 m	5.7 m	3.4 m	6.8 m
1	8.6 m	4.3 m	7.1 m	4.8 m	5.7 m	5.7 m	4.8 m	7.1 m	4.3 m	8.6 m
1.5	12.8 m	6.4 m	10.7 m	7.1 m	8.6 m	8.6 m	7.1 m	10.7 m	6.4 m	12.8 m
2	17.2 m	8.6 m	14.3 m	9.5 m	11.4 m	11.4 m	9.5 m	14.3 m	8.6 m	17.2 m
3	25.6 m	12.8 m	21.3 m	14.2 m	17.1 m	17.1 m	14.2 m	21.3 m	12.8 m	25.6 m

Methodology of Part Two

Width/depth ratio analysis was performed on 13 office rooms in multi-storey and high-rise office buildings in Xi'an. The proportion of office rooms with a width/depth ratio between 1: 1 and 1: 1.4 accounted for 86% of all the offices in multi-storey buildings, of which office rooms with a width/depth ratio of 1: 1.1 accounted for the highest proportion. The proportion of office rooms with a width/depth ratio between 1: 04 and 1: 1.08 accounted for 83% of all the offices in high-rise buildings, of which office rooms with a height of 3.6 m accounted for 54%. Office rooms in high-rise office buildings are thus mostly large-width rooms, and office rooms in multi-storey office buildings are mostly large-depth rooms. The differences between the width and the depth of offices in high-rise buildings and multi-storey buildings are mainly due to the structural and auxiliary space layout.

The simulated office has a width/depth ratio of 1: 1.1, width of 7.8 m, depth of 7 m, height of 3.6 m, surface area of 54.6 m^2, and volume of 196.56 m^3. According to standard, the per capita occupation of the building is 10 m^2/person, so the office can accommodate 5-6 people.

Orientation variables are 30° west of south, 15°west of south, south, 15° east of south, and 30° east of south. The windows are located in the centre of the external walls, with window-wall ratios varying from 20% to 80% in intervals of 10% (see Figure 1).

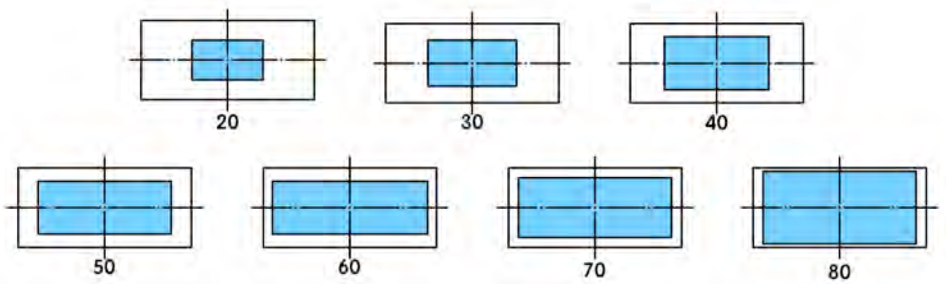


Figure 1. Examined window size variations. Amounts expressed in percentage Window-wall ratio(WWR)

Simulation tools – DesignBuilder and DAYSIM

DesignBuilder software is a tool for predicting and investigating building energy consumption. The computing engine is EnergyPlus, which provides information regarding climate, building, and thermophysical properties of construction, operational systems, and HVAC equipment. The simulation results are output as visual graphs, tables, and data.

DAYSIM is an analysis tool for lighting and illumination developed by the National Laboratory of Canada and the Fraunhofer Institute for Solar Energy Systems in Germany, which can be used to analyse the annual dynamic lighting level of buildings. It uses the Perez all-weather model for sky luminance and can comprehensively compute the impact of direct light, diffuse light, and ground-reflected light on indoor daylighting throughout the year under overcast, sunny, cloudy, and other sky conditions.

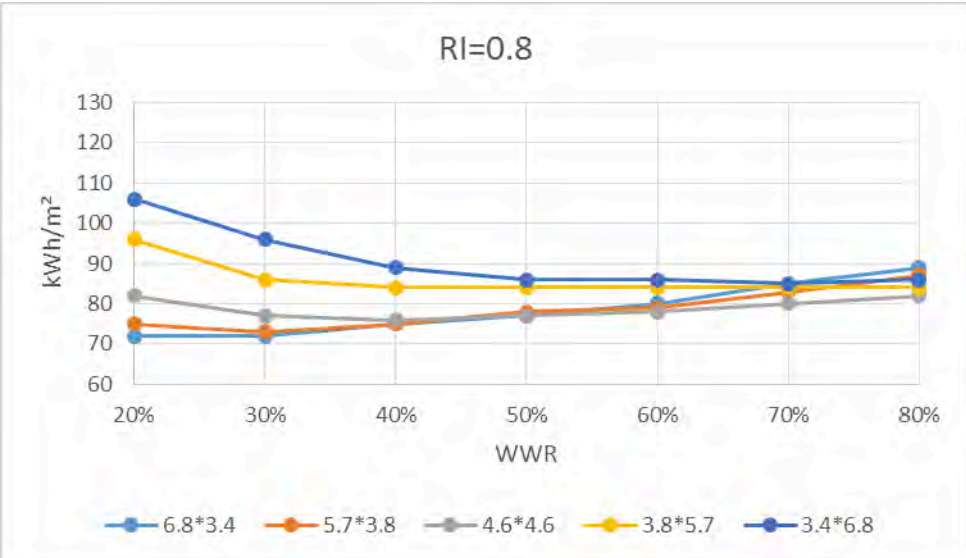
Simulation results

Results of Part One: the impact of room index and window-wall ratio on the photothermal performance of office rooms

The average brightness of the sky is clearly most intense in the south, so the UDI>2000 and DAmax of a south-facing office room are both 0, with no glare in the south. As the window-wall ratio increases, the introduction of solar radiation and natural light increases, heating energy consumption and lighting energy consumption demonstrates a decreasing trend, and cooling energy consumption shows an increasing trend(see Figure 2).

When the RI is 0.8 or 1, the total energy consumption of large-depth office rooms and large-width office rooms is inversely proportional to the window-wall ratio. In other words, the total energy consumption of large-depth office rooms decreases as the window-wall ratio increases, and energy consumption is lowest for a window-wall ratio of 60%-80%; the total energy consumption of large-width office rooms increases as the window-wall ratio increases, and energy consumption is highest for a window-wall ratio of 30% -50%. Large-depth rooms require a large fenestration area to introduce more natural light to lower energy consumption. Large-width rooms are more suitable to a smaller fenestration area to control the introduction of natural light to avoid overheating the room.

When the RI is 1.5, 2, or 3, energy consumption is lowest when the window-wall ratio is 50%-70%. This type of office fits the scope of a large-scale open space, and the increased introduction of natural light will reduce energy consumption, so total energy consumption increases as the window-wall ratio increases. The decrease in energy consumption is most significant in large-depth office rooms with a W: D ratio of 1: 2, and total energy consumption decreases by 7%, 9%, 13%, 16%, and 23%, respectively, when the RI increases from 0.8 to 3.



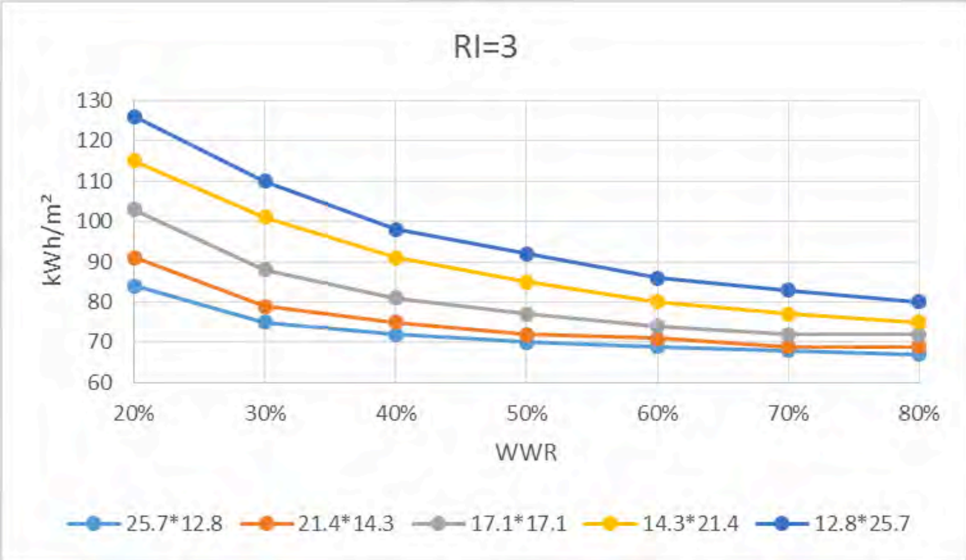


Figure 2. the impact of room index and window-wall ratio on the total energy consumption

The heating energy consumption of office rooms tends to decrease as the window-wall ratio increases, regardless of the magnitude of RI values. When the RI is 0.8, heating energy consumption is as high as 52kWh/m²; and when the RI is 3, heating energy is as low as 21 kWh/m². As RI values increase, the decline in heating energy consumption gradually slows. When the RI is 0.8, heating energy consumption can be reduced by 32%; however, when the RI is 3, heating energy consumption can only be reduced by 8%.

The cooling energy consumption of large-width office rooms and square office rooms increases as the window-wall ratio increases. When the RI is 0.8, 1, or 1.5, the cooling energy consumption of large-depth office rooms increases as the window-wall ratio increases. When the RI increases to 2 and 3, the cooling energy consumption of large-depth office rooms decreases as the window-wall ratio increases. As RI values increase, the decline in cooling energy consumption gradually slows. When the RI is 0.8, maximum cooling energy can be reduced by 48%; however, when the RI is 3, maximum cooling energy can be reduced only by 21%.

RI is proportional to lighting energy consumption. An increase in RI values means that the room scale increases, so lighting energy consumption gradually increases. As the window-wall ratio increases, more natural light is introduced into the office rooms, and their UDI100-2000 and DAcon increase.

Results of Part Two: the impact of window orientation and window-wall ratio on the energy consumption and lighting environment of a nearly square office

Using 5 different orientations and 7 different window-wall ratios as variables, we conducted a total of 35 energy consumption and lighting simulations, including DAcon and UDI simulations for each individual office room, a simulation of the average total annual energy consumption per square metre, and a simulation of average annual energy consumption per square metre for heating, cooling, and lighting, respectively.

According to the simulation results, the orientation corresponding to the lowest level of energy consumption is south and 15° east of south, followed by 15° west of south and 30° east of south. The orientation corresponding to the highest level of energy consumption is 30° west of south. The reason is that the western orientation has the longest daily duration of solar radiation, resulting in the highest level of cooling energy consumption. Solar radiation is most intense at 30° west of south, resulting in an increase in cooling energy consumption. The optimal window orientation in the Xi'an area is south and 15° east of south, and corresponding energy consumption is lowest for a window-wall ratio of 50%-70%(see Figure 3).

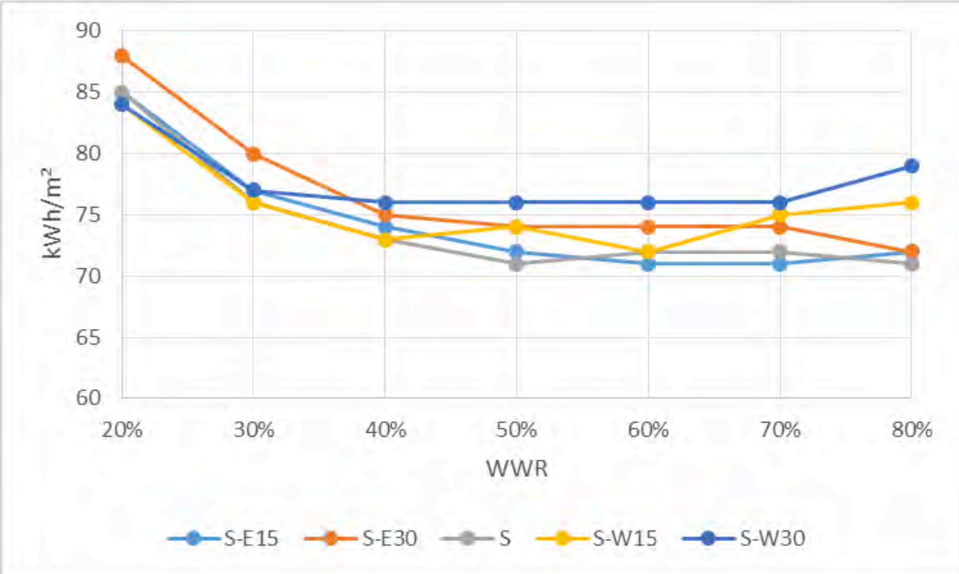


Figure 3. Energy consumption corresponding to the five different orientations

Table 2. Useful daylight illuminance UDI $_{2000}$ corresponding to the five different orientations

UDI>2000 / WWR	S	S-E15	S-E30	S-W15	S-W30
20%	0%	7%	2%	71%	72%
30%	0%	17%	7%	71%	72%
40%	0%	26%	18%	71%	72%
50%	0%	41%	30%	71%	72%
60%	0%	51%	44%	72%	72%
70%	0%	54%	46%	72%	72%
80%	0%	55%	49%	72%	72%

The heating energy consumption of offices with east-trending orientations is higher than that of those with west-trending orientations. The UDI>2000 of south-facing office rooms is 0, while the UDI >2000 of office rooms facing 15° or 30° east of south is up to 55%, and the UDI2000 of office rooms facing 15° or 30° west of south is 71%(see table 2). The orientation corresponding to the lowest frequency of glare occurrence is thus south, followed by east of south. The orientation corresponding to the most severe glare is west of south, so external shading for office rooms facing this direction must be installed in order to block direct light. In summary, the optimal orientation is south, which corresponds to optimal daylighting quality, least glare occurrence, and lowest energy consumption.

Conclusion

The simulation results show that differences in energy consumption are caused by differences in window-wall ratios, office room geometry, and window orientation. The energy consumption of office rooms varies based on room geometry, and a suitable window-wall ratio should be selected to reduce total energy consumption. A southern orientation is optimal in terms of daylighting and energy consumption, followed by 15° east of south, although glare has to be avoided in this orientation.

The energy consumption of mall-scale large-depth office rooms in the Xi'an area decreases as the window-wall ratio increases, and their optimal window-wall ratio is 60%-80%; the energy consumption of small-scale large-width office rooms increases as the window-wall ratio increases, and their optimal window-wall ratio is 30%-50%. The energy consumption of large-scale offices and square offices decreases as the window-wall ratio increases, and their optimal window-wall ratio is 50%-70%. The total energy consumption of large-depth office rooms decreases more rapidly than that of large-width office rooms as the window-wall ratio increases. In other words, the rate of decreases of total energy consumption as the window-wall ratio increases follows the order of large-depth rooms>square rooms>large-width rooms from high to low. As RI values increase, that is, as room scale increases, heating and cooling energy consumption decline gradually slows. The RI is proportional to lighting energy consumption, as lighting energy consumption is likely to increase as room scale increases.

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Sustainable eco-architecture for Sustainable eco-tourism: the Strategic Plan and pilot projects of Asinara Island

Antonella Trombadore[1], Marco Sala[1] and Pier Paolo Congiatu[2]

[1] ABITA Interuniversity Research Centre, Faculty of Architecture, University of Florence, Italy antonella.trombadore@unifi.it
[1] ABITA Interuniversity Research Centre, Faculty of Architecture, University of Florence, Italy marco_sala@unifi,.it
[2] Ente Parco Nazionale dell'Asinara, Porto Torres, Italy, congiatu@asinara.org

Abstract: The project is mainly concentrated to create a wide Strategic Plan and Pilot Project for the small island in Sardinia, Italy. In the two last centuries the Island hosted several prisons but now it becomes a Natural Park, famous for environmental quality and biodiversity. Its few built-up areas represent an enormous potential and the administration is oriented to explore the impact of an eco-tourism attractive model, thinking out a Strategic Plan for a self-sufficient island, implementing energy efficiency and architectural integration of renewables, suggesting new activities and functions but with extreme care towards their cohesion with the environment and the biodiversity. The integrated approach will generate more effective architectural design strategies, green infrastructures and technological solutions: building integrated PV and mini-wind turbines, a broad water-harvesting network, waste management and mobility plan, for a deep reduction of CO2. The retrofitting building concept focused on naturalistic experience, offering beautiful and wellness luxuries, exclusive green suites and agri-therapy for children. It concentrates primarily to improve the efficiency of 3 buildings blocks, with high attention to envelopes performance, integrating green space, green roof and facade, as well as some passive bioclimatic technologies to reach a full-scale of comfort inside.

Keywords: sustainable architecture, low energy building, building integration of solar and passive systems, Sustainable Tourism, Eco technologies

The challenges of Mediterranean Islands

In the Mediterranean area you can identify at least three different types of smaller islands, characterized by ecosystems and environmental heritage of great value, with a long and troubled process of historical sedimentation settlement. Today almost all of these islands are considered protected natural areas, such as Montecristo, the former penal colony of Pianosa and Asinara and traditional tourist islands as Giglio, Capraia and Maddalena. Small islands are still full of stories of treasures, memories and symbols that have undergone a process of transformation in recent years, often uncontrolled and characterized by fragmented management. In a perspective of sustainable development, it becomes necessary to stimulate the regenerative capacity of territories and natural resources, for local identity development in a spirit of cooperation and community involvement. In this process it is necessary to involve actors other than the public administration and SMEs playing a key role in the implementation and activation of local development.

The Asinara Island, located in the north-west of Sardinia, which includes the National Park of Asinara, has a surface of 51,9 square kilometres, formed by four minor mountain systems that are surrounded and linked by a narrow and flat coastal belt. The marine island environment represents an unicum in the Mediterranean area from a geological point of view, as well as its flora and fauna, both on land and sea, given the state of its territorial naturalness and outstanding presence. The island of Asinara in different centuries underwent alternation of cultural influences, creating a succession of different social dynamics of communities and settlements: from Cala Oliva as the village of Ligurian fishermen to various hospitals in the first and second period, as well as Cala Reale and the agricultural structures of Campu Perdu and Santa Maria, and the prison sectors of Trabuccatu, Fornelli, Tumbarino.

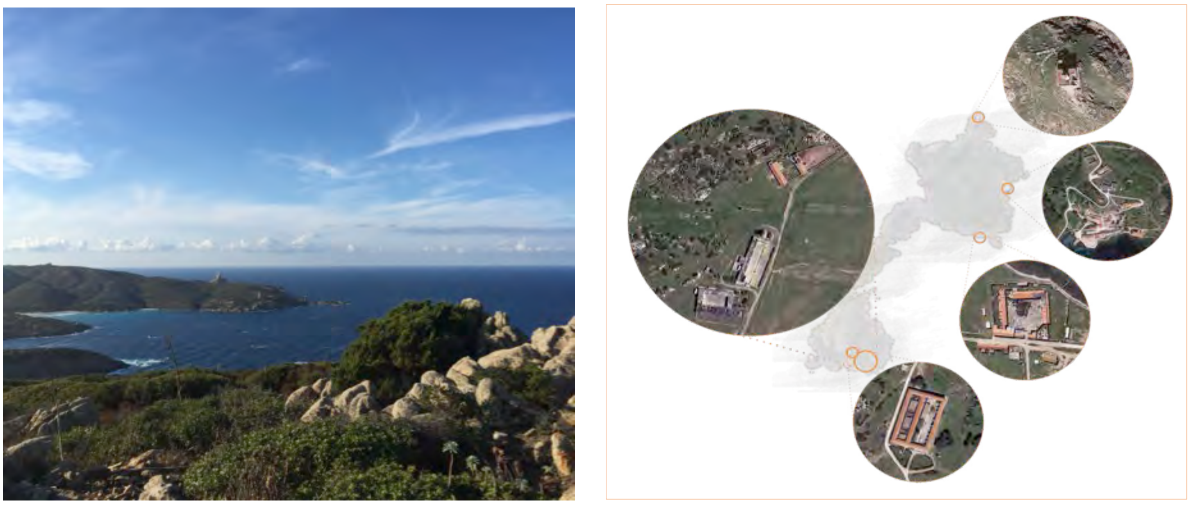

Figure 1-2. General view of the Asinara Island and 4 main prison structures

Despite the diversity of the social structure the islanders have allowed us to maintain a dynamic balance between nature and man, being able to manage the entropy of the system in all its complexity, ensuring at the same time the development of agricultural activities as economic and functional aspects of the island and the island life.

The establishment of the Asinara National Park has fortunately slowed down the phenomenon of massive tourism and led to a reversal of the trend, aiming at stimulating a growing demand for high environmental quality services, more aware of the rural and natural resource ecosystems, with a scientific approach and an international feel.

The Asinara territory can be an ideal and real testing ground for the international sharing and the promotion of a sustainable use pattern of low density territories and man-made high concentration of natural and cultural resources. A laboratory in which to test both systems of governance is the creation of ecological networks for smart resource management, integrated with business and Km0 agricultural model (local production of food and beverage). In this way it could trigger a virtuous process that brings the revitalization of the area, improving the competitiveness of local SMEs operating levels in the chain of tourist use. Thanks to the experimentation of a governance strategy and a participatory model of innovation and inclusive development, it becomes possible to enhance the system resources as well as the economic structure towards a model of eco-tourism and responsible tourism, which will produce in the short and medium term an increased green growth in a sustainable development perspective.

Figure 3. Flow chart of main drivers to stimulate regeneration process

The island in the island: Network of Cluster to stimulate the regeneration process.

The strategic plan designed to initiate a rebirth and Asinara island regeneration process, through the development of functions compatible with the fragile ecosystem, is based on the introduction of new activities, eco-compatible and integrated with the environment. However, to predict and to best design the arrangement and management of these new activities, it has developed an additional level of planning: blending various activities into Clusters and Networks. The term cluster is redefined in this case and applied to the particular natural and cultural context in which we find ourselves. It is to divide the island into several parts, which are considered self-sufficient but closely connected and collaborating. This brings us to the concept of the island in the island: a complex of buildings, structures, agricultural and natural areas full of all types of services and activities related to its function. This self-sufficiency is related to one (or more) particular activity, well defined, with a series of facilities dedicated to it. These structures are usually obtained from the pre-existing buildings. Each cluster has a main theme, and in some cases we have an additional division, as some activities are located in various parts of the island.

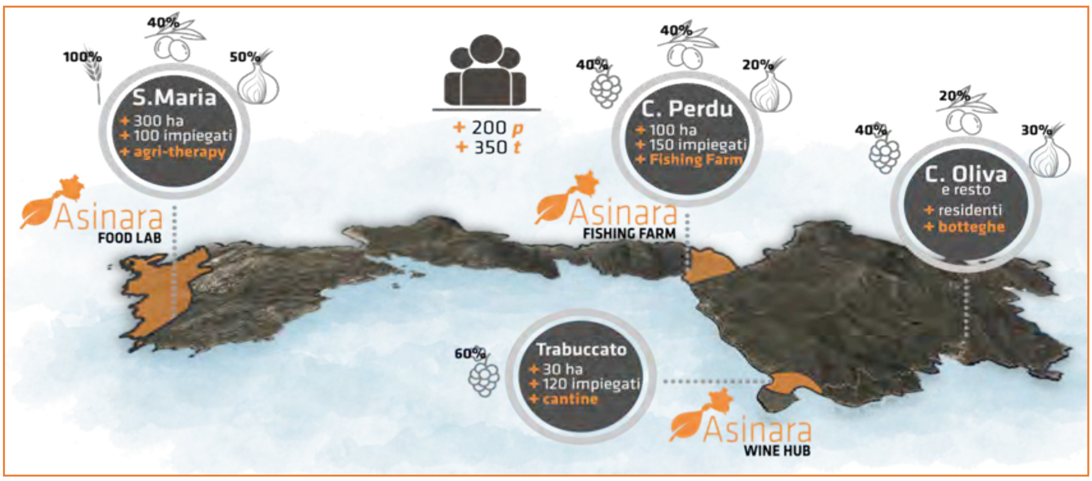

Fig. 4 Cluster distribution, related activities and personal involvement

The project concentrated mainly towards creating a wide Strategic Plan for the island regeneration: its main goal was creating completely new activities and functions that are compatible both with its touristic potential and especially with its natural fragility. These functions have been planned in order to give life and continuous activity to the island, but with extreme attention towards its cohesion with nature and biodiversity. 4 Pilot Projects as Food Lab, Fishing Farm, Wine hub, Wellness centre.

These various activities have been supported by a complex network of structure and services, dedicated to maintaining the island's ecosystem intact, and improving its offer and abilities to create both natural and commercial environment. The Strategic Plan has been developed with various strategies for reaching a sustainable and self-sufficient island, and has included various technological solutions. For example, there is an extensive use of building integrated PV and wind turbines which are inserted in architectural and urban environments in a non-invasive way. Other strategies include a broad water-harvesting network that includes harvesting rain water from roofing, in urban areas, and especially in agricultural areas, given its high need and waste of water used for irrigation. Other strategies include a revised mobility plan that points towards complete elimination of CO_2 emissions, giving priority to use of electric cars, as well as encouraging cycling and walking, given various beautiful natural areas on the island.

Fig. 5 The location and activities of the Cluster in the Master Plan

Food Lab - Santa Maria Pilot Project

The focus of the pilot project was the revitalization of the former prison sector Santa Maria as an international laboratory for ecotourism. This complex, located in the south of the area, has been used in the past as a farm for a particular group of inmates, and is situated near a field of nearly 200 hectares that can be turned into an agricultural farm complex. The concept behind the project was about creating a structure that is both productive and commercial, that offers a unique and naturalistic way of approaching and learning processes of agriculture, but that also offers beautiful and relaxing luxuries such as a slow food restaurant, exclusive green suites, a kitchen laboratory and an agri-therapy for children. It has been conceived as multifunctional set of buildings with green public spaces in-between, perfectly connected and able to offer a full set of activities and leisure for tourists as well as researchers. The building is a prison structure that has been revitalized and refreshed to house a slow-food restaurant and various suites for visitors. The project leaves internal disposition practically intact, but intervenes on buildings facades, making it much more open and illuminated, creating almost semi-open spaces that collaborate perfectly with the green surrounding them. These facades have been elaborated with some air and light-treating technologies, in order to reach a full-scale comfort inside the suites and restaurants. These technologies include:

- ***EvaCool***, a separated façade system built with tube structure that envelopes plants and hygroscopic materials that help cool air via evaporation, and channel it inside the building with specially designed cross-ventilation systems;
- A special ***in-suite greenhouse*** that uses a ***skylight for water harvesting*** and for better illumination, increasing the climatic comfort in the suite as well as indirect and diffused illumination;
- Inside and outside ***gardens*** that house a terrace-based water harvesting system.
- ***CanoPV+,*** a modular, tree-like canopy structure, with integrated photovoltaic cells that serves both as energy efficient element as well as for creating shaded spaces in outside gardens.

Fig. 6 -7 General view of the location and activities of the Cluster in the Master Plan

GreenRoom

It can be considered a nucleus of various technological solutions, with the scope of bringing perfect comfort and ideal thermal state inside the suites of the A Block. As suggested by its name, GreenRoom is characterized by a special in-suite greenhouse that uses a skylight for water harvesting and for better illumination, increasing the climatic comfort in the suite as well as indirect and diffused illumination.
Standing between the in-suite bathroom and the bedroom, it has a wide array of functions:

- The greenhouse serves as a water harvesting system, with rainwater being collected from the roof, through the skylight, and to the vegetation. The humidity of the plants helps cool down the ambient and provides a unique experience with the bathtub in-between the high vegetation;
- All the excess water that is not absorbed by vegetation is brought down to the general water harvesting system;
- The skylight at the top of the structure helps bring more natural light to the interior.

- With its glass structure and precisely inclined roof section, the GreenRoom helps diffuse natural light into the bedroom, giving more light in the morning period but maintaining low exposure during warm hours;
- The exterior of these suites has been enriched with a shading structure made primarily of wood and steel. It has a mobile front element that helps direct light throughout the day, contributing to the general comfort of the interior.

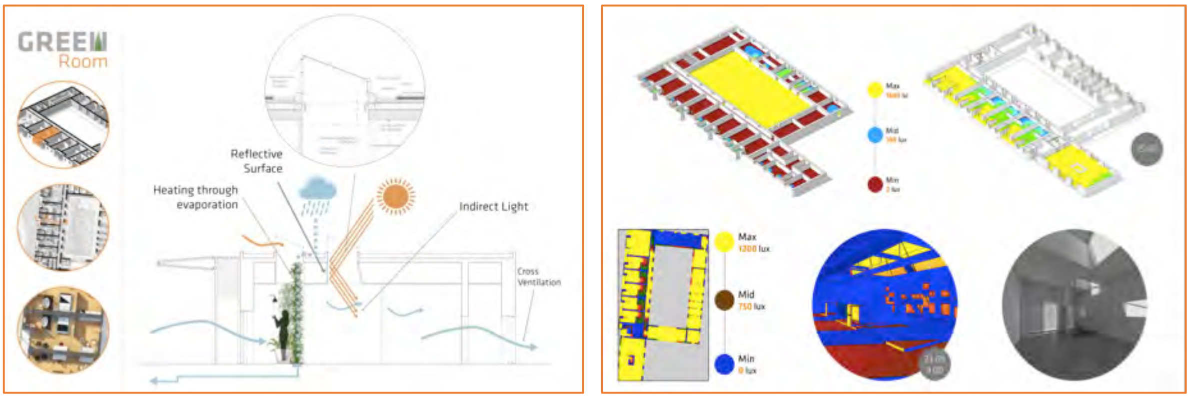

Fig. 8-9 Strategies of Green Room and Daylight evaluation

EvaCool

A separated facade system built with tube structure that envelopes plants and hygroscopic materials. These materials help cool the air via evaporation, and channel it towards the interior of the building with specially designed cross-ventilation systems.

The idea behind the creation of EvaCool is based on the need to create a new solution for the main facade of A Block, along with the intent of giving thermal comfort to the interiors. It is characterized by a tubular 3D structure with vegetation between the tubes. The tube system is connected to the green roof that collects rainwater, then channels it to the tubes. From there, part of the water is sprayed on the vegetation and the rest continues to the main harvesting system. This way, hygroscopic materials in-between the vegetation and tubular structure make contact with water, enabling them to instigate evaporation. The warm air gets colder and subsequently enters the interior via specifically-designed openings above the doors. This system, combined with the cross-ventilation provided by aligned openings, assures thermal comfort inside the right wing of the building.

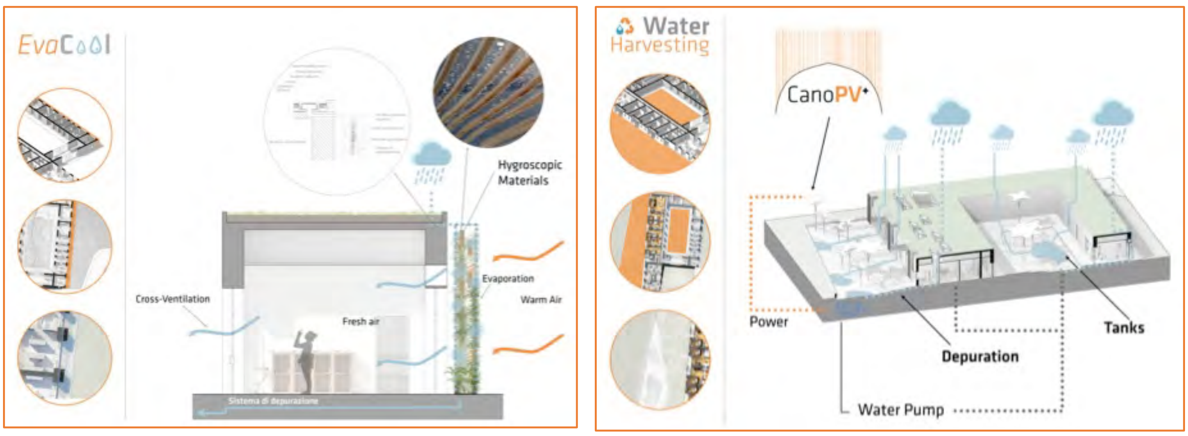

Fig. 10 -11 Strategies of Evaporative Cooling and Water Harvesting

ComfortRoom

The B Block houses another set of suites that have been designed with an effort to provide a complete thermal comfort. The ComfortRoom is characterized by an external shading structure with mobile elements that provide shading as well as rain protection and ventilation. Steel elements of this external structure is a part of general water harvesting structure that helps provide water for irrigation of nearby vegetable gardens. The original openings on the back side have been modified in order to provide more daylight and also to improve the cross-ventilation system, guaranteeing major comfort inside the suites.

Fig. 12 The location and activities of the Cluster in the Master Plan

General Water Harvesting System

All the above-mentioned technologies are a part of a wider system for collection, depuration and subsequent re-use of rainwater. This water-harvesting system interacts directly with the two main gardens (one inside and one on the outer side) that house a terrace-based water filtration system. The rainwater is collected both from the roof structure and from the gardens themselves. The green roof helps cleaning the rainwater with its filter layers. The water continues and is conveyed through the EvaCool and GreenRoom systems, where it has an important function for thermal comfort regulation. The excess water then continues and is attached to the underground system and conveyed through terraces inside small tanks that are integrated in the gardens. Water is then pumped from the tanks back to the building using energy provided by the CanoPV+ structure positioned in and around the gardens, contributing to the optimal eco-sustainable result, taking into account both water harvesting and energy efficiency.

Hybrid Heating System

Heating and warm water system is also designed to contribute to energy saving goals of the project. It consist of a hybrid solution that minimises the electric energy consumption, uses energy-efficient heat pump, but also includes a special solar thermal system to help contain energy usage. The solar-thermal modules are positioned on the left wing of the green roof, and interact with the ceiling system that houses all the installations.

This system should contribution to minimizing electric energy consumption, and can go as far as making it completely unnecessary during main summer months. Combined with the energy provided from CanoPV+ modules, this system further develops the eco-sustainable nature of the project.

Fig. 13 The location and activities of the Cluster in the Master Plan

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Solar control design by matching criteria between its shading mask and the shadow desirability schedule to improve natural daylighting in an office building in the tropic

Jorge Hernán Salazar Trujillo

Profesor Titular, Grupo de Investigación EMAT, Facultad de Arquitectura, Universidad Nacional de Colombia, Medellín. jhsalaza@unal.edu.co

Abstract: Natural daylighting issues now are included in the design goals of shading devices, but the meteorological data needed to simulate its daylighting performance are hardly included during the early stages of the architectural design process. When a shadow device is perfectly sized and placed, it does not mask more sky than needed, nor does it allow unwanted solar entrance. To keep undesirable masks at their minimum while keeping desirable masks at their maximum, a perfect coupling is needed, something rarely achieved intuitively. An optimization method starting from minimum input was developed, useful when many of the project's energy efficiency decisions are still to be made. The Solar Coupling index here defined and applied, assess the deviation of an architectural alternative from the "perfect match": the best possible correspondence between the masked region and the shade desirability schedule. The methodology was applied in a 65.000 m2 office tower in Medellín Colombia, applying for LEED GOLD Core & Shell v3. The paper shows the evolution of the facade design process, illustrating the counterbalance between shading, natural daylighting exploitation and required aluminium expenses, illustrating the possibilities of the Solar Coupling method as an early design tool.

Keywords: Shadow efficiency, Shading device, Solar control, Daylighting, Sky visibility

Introduction

To avoid direct solar radiation income during the periods when solar gain will be unwanted is a basic premise of energy efficient buildings. If solar control is handled with high shading coefficient glass, the thermal load reduction will be a transmission-conduction issue. Optionally, when the envelope design includes shading devices, the search for energy efficiency becomes essentially a geometric issue. In this second case, the aim will be to prevent visibility towards the sectors of the sky dome where solar trajectories happen during time periods the shadow will be desirable. If visibility restriction towards those "unsuitable" sectors of the sky dome is not complete, the solar control device will mask a smaller portion of the sky dome than needed, providing insufficient solar control. Shade shortcoming will evolve in higher cooling power needs, higher initial investment in equipment, higher energy consumption of the mechanical cooling system and unwanted solar intrusion. In this situation, it is almost sure that users will try to block annoying solar intrusion by closing curtains or blinds, preventing daylighting and visual contact with the surroundings (William et al, 2012). The opposite situation could also happen: if the shading device masks a broader part of the sky dome than needed, it will include regions where there will not happen unwanted solar trajectories, precisely where the possibilities of taking advantage of diffuse light are the highest (Lan, 1986) (Bodart et al., 2002). Unnecessary sky masking will reduce the possibilities for natural light exploitation and greater use of daytime artificial lighting will be necessary (Reinhart et al, 2006).

Because excess or insufficiency in sky masking has a negative impact on energy efficiency and environmental quality of a building, the ideal situation is to design openings that maximize diffuse lighting while guaranteeing the absence of solar intrusion into the building. Interdependence relationship between diffuse lighting exploitation and shading depends on the geometrical configuration of solar control devices but it is strongly modified by changes in the facade's orientation, opening's shape, latitude and site skyline, making the task little intuitive during the preliminary drawings stage. High level of realism is needed for modelling natural lighting from climatic information (Mardaljevic et al, 2009) and that is also the case for thermal modelling (Monteoliva et al, 2012) (Rogers, 2006). Once the design team is finally prepared to provide the architectural information needed for carrying out the dynamic simulations of energy performance and conjugated lighting, the design flexibility is not as high as it was during the early design stages because the project has already gathered enough decisions that limit design choices.

Close correspondence between needed and provided shadow, only depends on the similarity between the masking originated by a shading device and the shade desirability schedule. This compromise relationship reaches an optimal point when a solar control device prevents any solar intrusion without limiting visibility towards any other sector of the sky dome (Figure 1). Reached the maximum level of coupling, mobile shading devices, selective glazing or automated systems would be the ways to continue increasing energy efficiency of an optimized shade (Nielsen et al, 2011). Because such perfect match is rarely perfect, it is important to calculate the bias from this ideal situation and define a metric of the situation since in any of the two scenarios: deficiency or excess, the result will be an increase in the energy needs. Once the design process reaches enough detail such condition is detected easily, but now the adjustment needs will be expensive in time and team effort.

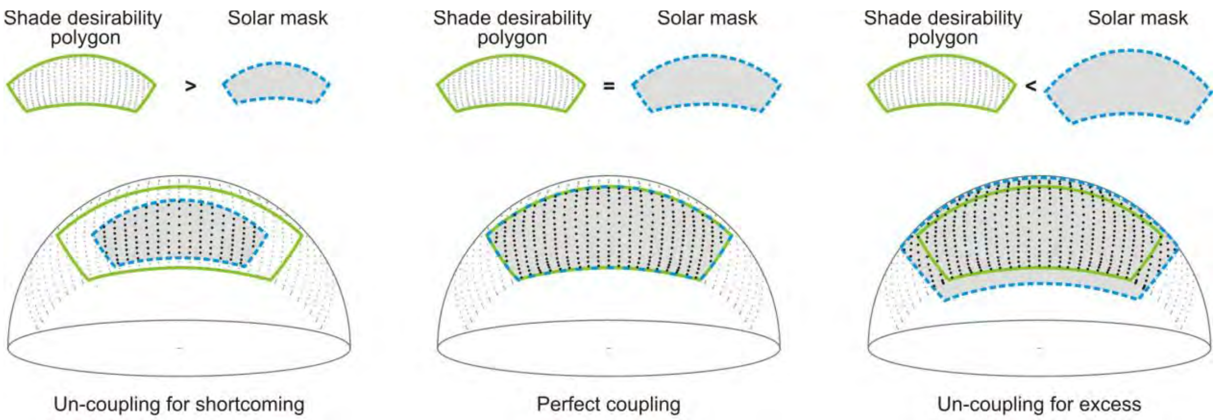

Figure 1 – Relationships between lighting exploitation possibilities and shade. Left: Un-coupling by shortcoming, when the shade desirability polygon is greater than shadow device´s solar mask. The room will be luminous but overheated. Centre: Perfect match. Right: Un-coupling by excess: the shading mask exceeds the desirability schedule. The room will be over-shadowed. Source: Author (2017).

Objective

Early decisions have the strongest impact on design. If the initial drawings provided to start energy detailed studies guarantee the Solar Coupling of every opening is close to its optimal, the starting point of HVAC designers would be better tuned and a solution could be reached in a less expensive way. Taking advantage of the fact that Solar Coupling is just a geometric property and that its calculation requires little input information, an analysis method allowing an early diagnosis of the relationship between natural lighting and shading was developed. The aim was to create and test a tool useful during the facade conception, promoting decisions that favour daylighting and solar protection. The results obtained help the architecture design team to identify the most advisable alternative and find equivalent solutions from the perspective of the natural lighting-shading relationship, quantifying the shade improvement margin of any opening, no matter the geometrical complexity involved.

Methodology

Shading masks are a classic tool of solar design. Basic shapes collections are included in a great deal of Bioclimatic literature (Olgyay, 1963) (Lippsmeier, 1969) (Baruch, 1976) (Szokolay, 1977) (Yáñez, 1988). Superposing a shading mask over a solar chart and count masked solar positions is a simple way to estimate the efficiency a solar control device will have. Additionally, the counting of non-blocked positions is the simplest method to know its optimization margin. Solar Coupling calculations and the computer code that allows its practical application are based on the relationships between spherical polygons obtained from the shadow desirability schedule and the opaque elements surrounding every studied opening. In order to make the calculations, initial 3D polygons must be transformed in 2D shading masks. Transform three-dimensional opaque elements representing a shading device into their corresponding spherical polygons, required to divide every one of their sides into short segments. Once those segments were drawn, every vertex was transferred towards a spherical surface representing the sky dome using size relations between similar triangles from a point operating as the polar coordinate system origin (Figure 2). Using geometric transformations applied on individual points instead of deriving trigonometric functions for specific shapes, is what allowed calculating the shading mask for any opening, regardless of its geometric complexity.

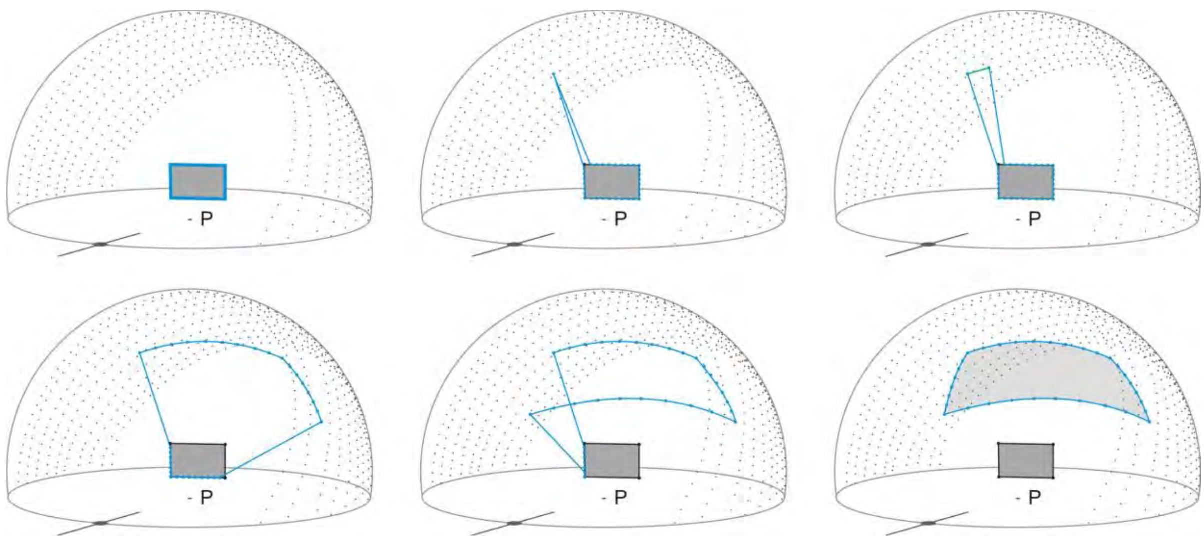

Figure 2. Drawing of a spherical shading mask. Transformation of any opaque element into its corresponding masking polygon from point P. Source: Author (2017).

To calculate masked sky regions, thousands of randomly distributed points on a spherical surface representing the sky dome were counted. Applying an algorithm previously developed that allows to determine whether or not a point is included in a closed polygon (Salazar, 2009), the belonging condition of every point to every group of spherical polygons was verified to classify them into four sets: Shaded (points included in the masked region and belonging to a shadow desirability polygon). Not Shaded (not included in the masked region and belonging to a shadow desirability polygon). Visible (not included in any masked region) and Not Visible (included in the masked region but not belonging to any shadow desirability polygon). This last set of points corresponds to the part of the sky unnecessarily masked. The counting of points belonging to those four sets allowed to calculate the proportions among the different regions in which the sky dome is divided by an opening, its shading elements and the neighbour objects. The addition of those four percentages is always equal to the unit (Figure 3, left).

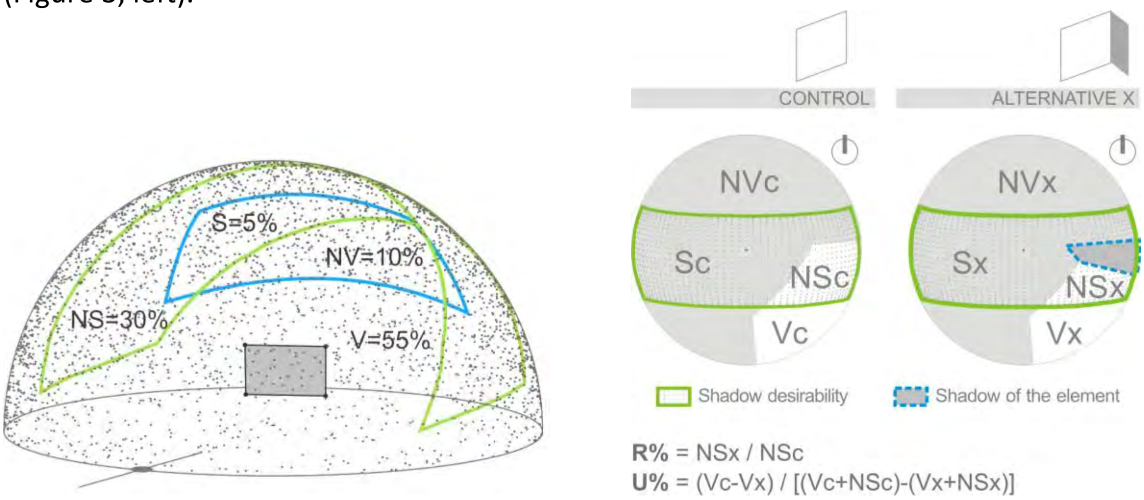

Figure 3: Left: Points classification depending on whether or not are included in the shading desirability polygon (green) and/or the shading mask (blue). Four groups were defined: Shaded (S), Not-Shaded (NS) corresponding to the shade shortcoming, Visible (V) and Not-Visible (NV) corresponding to the unnecessarily masked sky. Right: Remanence (R%) and Un-coupling (U%) of a shading element by means of the comparison between the studied alternative and a control opening used as a reference. Source: Author (2017).

Solar Coupling depends on masking polygons size and position. When shade sizing is done, the masked region at least should be as wide as the shading desirability polygon. This first condition is verified when the Not Shaded value (NS) is equal to zero. Besides, the masked region should not include portions of the visible sky dome, situation reached when the Not-Visible value (NV) is equal to zero. As can be noticed, the best possible condition happens when the masking polygons and the shading desirability polygons meet point by point. To define the Solar Coupling as a property of comparative nature, a reference case is necessary. The obtained values (Vc and NSc) from a control opening used as a reference and the subsequent values (Vx and NSx) from any opening, allowed calculating the Un-coupling U% and Remanence R% using equations 1 and 2. The former is defined as the percentage of the sky dome that has been masked even though it is not part of the shading desirability polygon. The last defined as the percentage of solar positions that should be blocked but have not been masked yet (Figure 3, right). Both values expressed as a percentage of the control opening.

$$U\% = (Vc-Vx) / [(Vc+NSc)-(Vx+NSx)] \quad \text{Eq. 1}$$

$$R\% = NSx / NSc \quad \text{Eq. 2}$$

Minimizing the un-coupling (U% close or equal to zero) while guaranteeing the shading conditions previously established (R%=0) is the path to design shading devices causing a minimal restriction to natural light exploitation. A maximal un-coupling (U%=100) means that the shading device does not block any additional part of the shading desirability polygon compared to the reference opening. A maximal remanence (R%=100) means that the alternative being evaluated does not offer any additional masking compared to the reference opening.

Results and discussion

To test the method three shade alternatives on a prototype square opening located in latitude 6.25°N were evaluated. The calculations considered three shade sizes in a progressive width of 0.50m, 1.0m and 1.50m and the Solar Coupling diagrams (Figure 4) show the obtained results. The reference opening: same size and orientation without any shadow element in front of it, is always located at the upper right side of every diagram, while the best possible value corresponds to the origin. The Un-coupling (U%) lies on the abscissas: as a point moves away from the origin, it will unnecessarily mask a greater part of the sky dome. The remanence (R%) is on the ordinates: as a point moves away from the origin, it will leave unmasked a greater part of the shading desirability zone.

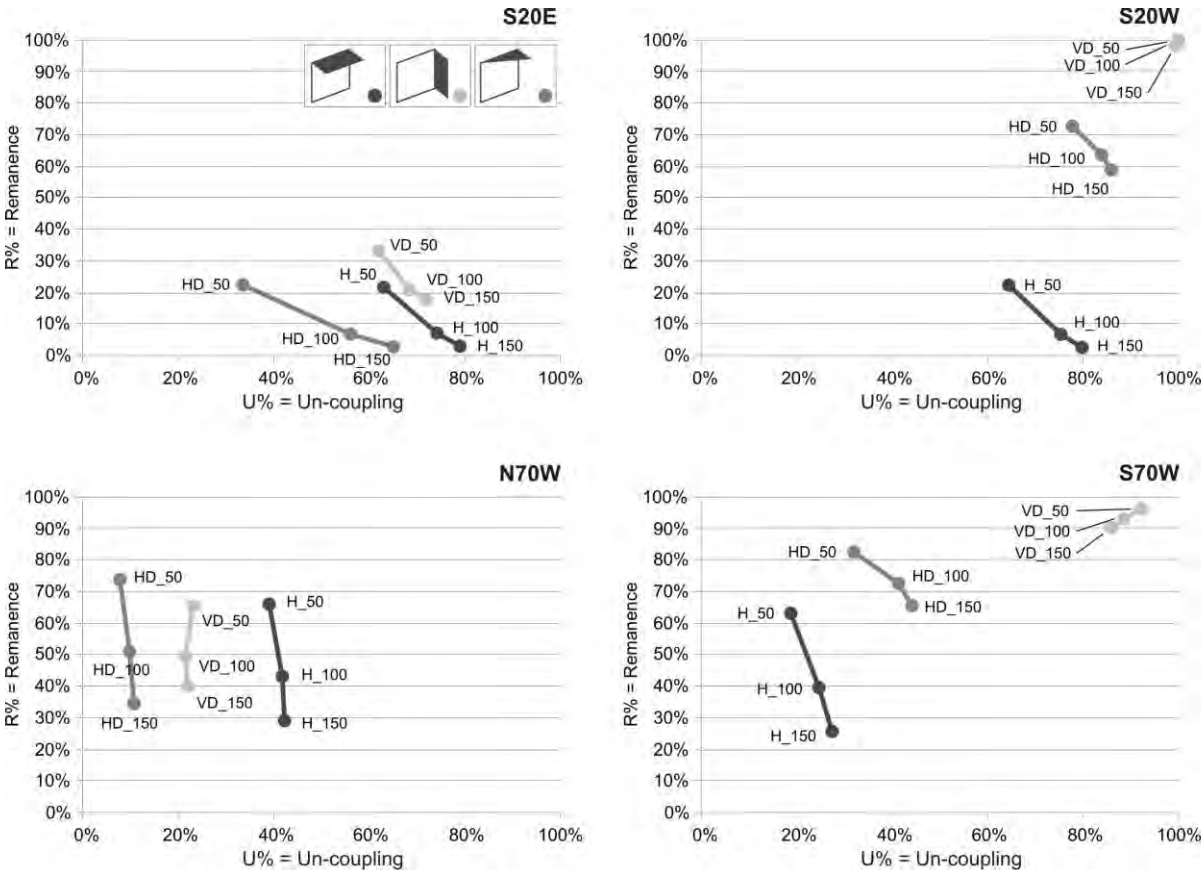

Figure 4. Solar Coupling Diagrams of a square opening facing different orientations in latitude 6.25°N. Three shading alternatives of increased width in cm were used: Horizontal overhang (H), Vertical fin (VD), and Triangular shade (HD). The control opening used as reference maintains size and orientation but lacks of any shadow element and its obtained value is always located at the upper right side of every diagram. The best possible Solar Coupling attainable corresponds to the origin. Source: Author (2017).

Points vertically lined up will generate equivalent unnecessary sky dome obstructions, but the one placed the lowest will have a better solar performance since it leaves fewer solar trajectories unprotected and, therefore, will generate less solar direct gains. Points horizontally lined up leave equivalent portions of the shading desirability polygon unmasked, but the one located farthest to the left will be preferable, since it will allow visibility towards a greater part of the sky dome and, therefore, will favour a higher level of daylight exploitation.

The prototype window test revealed significant differences between the shade alternatives evaluated. As can be noticed in figure 4, for a S20W square opening changing from 0.50m vertical elements to horizontal ones would reduce up to a fifth the solar income without important changes in its level of light exploitation. The situation is totally different in S20E openings, because same change would halve the natural lighting possibilities without any significant reduction in the solar gains. It is possible to make other comparisons, e.g. shape changes are more favourable than shading device enlargement in some orientations.

Figure 5. Left: Business Centre “Milla de Oro” designed by AIA in 2012 and located in Medellín, Colombia. Right: Built façade, corresponding to the alternative number 15 in figure 6. Photo: Valentina Zuluaga (2017).

Finished the test, the method was applied in the facade design of a 65.000 m^2 Business Centre located in Medellín Colombia (6.25°N, 75.6°W and 1550m above sea level). The “Milla de Oro” project, designed by AIA Architects and actually applying for LEED GOLD Core & Shell v3, proposed since the first sketches a high level of shadowing instead of the high reflectance glazing, the standard look of an office building in the city. A single 0.70m overhang at 2.70m height is the starting point of the analysis. The office towers have two west facing facades maintaining a single shade design in both orientations in order to have rounded corners. The South West façade has the highest solar exposure and the shading devices were designed under SW considerations. It explains why the obtained results are better than the North West results, where the façade is slightly overprotected and gets less natural lighting than the maximum for its orientation would allow (Figure 6).

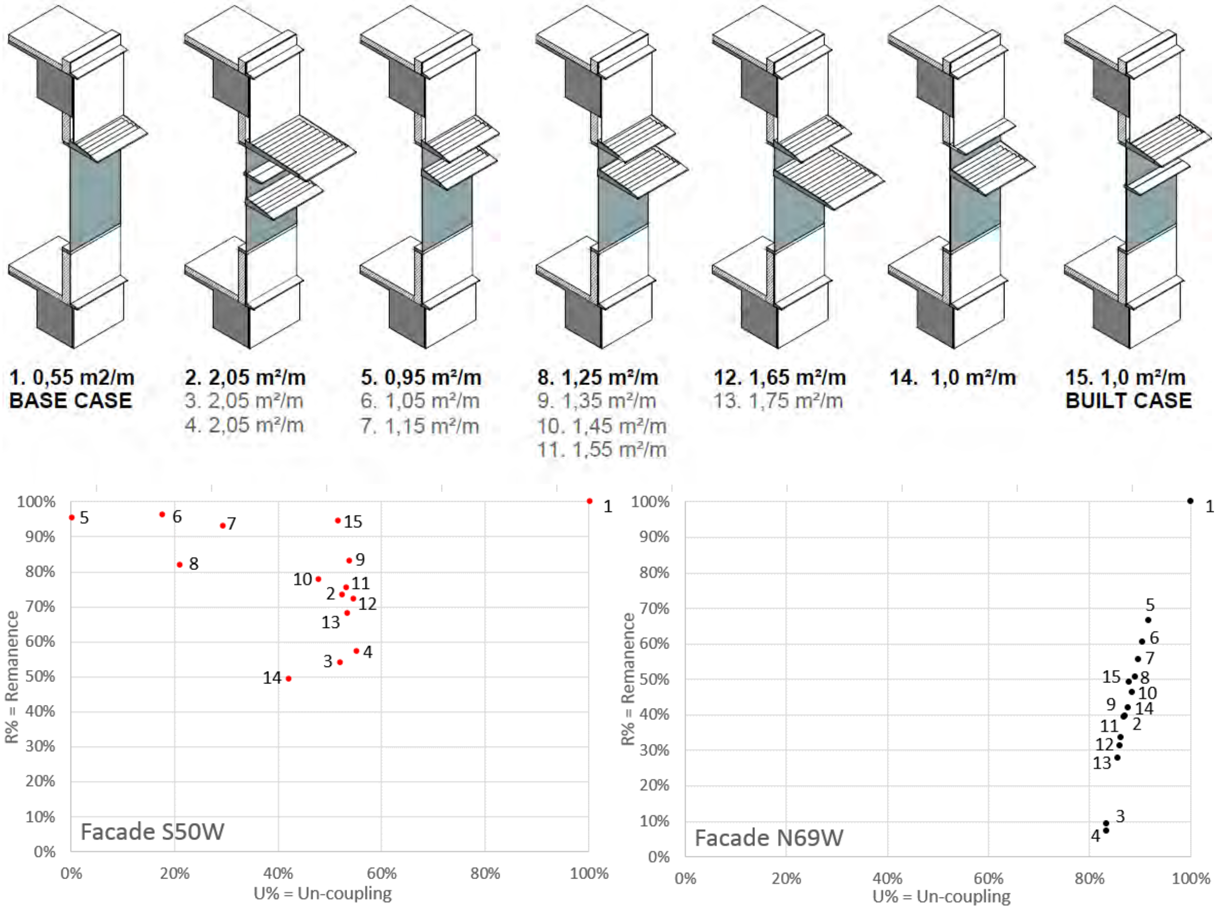

Figure 6. Sketches evaluated during the first design stages and its aluminium needs. Below, the corresponding Solar Coupling Diagrams in South West and North West facades. Source: Author (2017).

The 15 evaluated alternatives and the aluminium needs expressed in m^2 of aluminium per typical floor facade metre, reveal the explorations made during the early stages of the architectural design. In the beginning (alternatives 2, 3, 4) the aluminium needs were high, testing the possibilities of use clear glazing. The corresponding results (points 2, 3 and 4 in both diagrams) reveal the performance of design choices equally expensive. Once the aluminium investment needed to counterbalance the wind loads was included as a design variable, sketch number 5 show an aluminium cut off. Several choices considering two shelves and glazing as clear as possible (alternatives 6 to 11) were evaluated. Sketches number 14 and 15 show the final choices under consideration. From this point detailed thermal load calculation started, orientated to HVAC design and to define the final glazing specifications.

Conclusions

Show the Solar Coupling in an intuitive diagram, easy to understand even for people with basic knowledge on energy efficiency, allows that Architectural design teams interested in energy conservation promote lower energy demands from the early design stages. Starting from basic geometric information make possible to compare between similar façade sketches, identify the optimization margin and visualize the effectiveness of decisions oriented to minimize solar intrusion, maximizing the natural light exploitation possibilities and improving indoor environment conditions.

The method used to calculate the Solar Coupling in the Business Centre allowed to define numerically a minimal coupling threshold and to work to reach it from the early design stages. The typical un-coupling values in built facades frequently will surpass the ideal value, but the distancing from this theoretical situation constitutes an unbiased method to quantify the mismatch between the solar performance of any shading device and the best attainable condition.

To give opportune information according to design team agenda, a homogenous sky model was used to reduce computing time. Further improvements can be included (e.g. solar data, cloud coverage and ground reflections), but including climate data and materials optical properties would take out the method from the domain of the standard team that produce architectural sketches, leading the research to the natural lightning prediction area.

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Building Envelope Optimisation for Low-income Housing in Southern Brazil

Renata Tubelo[1], Lucelia Rodrigues[1*], Mark Gillott[1] and Miguel Aloysio Sattler[2]

[1] Department of Architecture and Built Environment, Faculty of Engineering, University of Nottingham, Nottingham, UK, * lucelia.rodrigues@nottingham.ac.uk.
[2] Núcleo Orientado para a Inovação da Edificação (NORIE), Universidade Federal do Rio Grande do Sul (UFRGS), Porto Alegre, Brazil.

Abstract: The need for more low-income housing accounts for 89.6% of the national Brazilian housing deficit, currently estimated at approximately 5.5 million units. New houses built in response to this demand should seek to deliver thermal comfort and energy efficiency to their occupants. In this paper, the authors use a low-income housing typology designed for the climate of Porto Alegre in southern Brazil as a vehicle to explore ways of optimising the building envelope to improve thermal performance passively. The concept of fabric first approach is explored, varying the levels of insulation and airtightness of the envelope as means of improving indoor environmental conditions and energy savings. The method used was dynamic building simulations, underpinned by empirical data and assessed for its thermal/energy efficiency and construction cost. The findings suggested that an optimised envelope can achieve an increase of the thermal comfort of up to 130%, and a reduction of the energy demand to negligible levels. The results demonstrated, however, that the envelope optimisation increased costs considerably. The results also suggested that there is a need for further investigation of infiltration levels in residential buildings in Brazil and their implications on the delivery of thermal comfort.

Keywords: thermal comfort, energy efficiency, low-income housing, building envelope optimisation.

Introduction

Brazil has a housing shortfall of 5.546 million housing units (Fundação João Pinheiro, 2011). The most affected by this shortage of housing is the low-income population, which represents up to 90% of the national deficit (UN-Habitat, 2013, Angélil and Hehl, 2014).

The housing deficit varies across the country and it is more expressive in the northeast of the country, where the poorest population are mostly found. However, it is in the southern part of the country where the delivery of the thermal comfort is a greater challenge due a more extreme climate. There, the housing deficit ranks 3rd and represents 10% of the national deficit (Fundação João Pinheiro, 2011). The great concern in the provision of these new low-income housing typologies in south of Brazil is related to the lack of adaptability to the climate and use of culturally accepted materials. In the city of Porto Alegre (lat. 30.05°S, long. 51.23°W, alt. 47m) the climate is characterised by both the existence of warm to hot summers that are also humid, and cold winters, and buildings are characterised by often conflicting solutions for dealing with heating and cooling demands.

The concept of the fabric first approach, which mostly considers an insulated and airtight building envelope, is used in this paper to support the argument for higher energy efficiency in Brazilian dwellings, despite these concepts are not vastly employed in Brazilian buildings yet, as shown in Tubelo et al. (2014).

Low-income Housing in Brazil

The main characteristics of low-income housing typology in Brazil when delivered or financed by housing programmes are its standardised nature, which is adopted in terms of typology and materials indistinctly across the country without minding climate and cultural differences.

In this context, the most common low-income housing typology consists of a 2-bedroom 1-floor detached building of an area larger than 36m^2 (Tubelo, 2016). The fenestrations of these low-income houses mostly do not exceed 2m^2 and are commercialised in standardised dimension due to the costs (Tubelo et al., 2016). The house eaves are built out of a minimum eaves requirement of 50cm length as suggested by Ministério das Cidades (2014), which allow the delivery of a certain degree of shading when combined to the typical small windows (Tubelo et al., 2016). However, this does not consider the house's orientation. These houses are mostly built with a layer of load-bearing hollow block wall of 14cm thickness with a layer of plastering of about 2cm of thickness each; windows are mostly made out of aluminium or steel with a 3mm single glass (Tubelo et al., 2016).

Data from low-income housing research suggests that these buildings have a high occupancy rate. Data from 2010 Census states that the average household in Brazil have 3.3 people (IBGE, 2010), but low-income housing have a much higher density. Previous research on low-income housing shows a occupancy rate of 1 person per 13m^2 (Cruz and Ornstein, 1995) but common practices in low-income housing could be 1 person per 9m^2 so it is not unusual to find a house of 36 m^2 with 4 people living in.

The case study: the Alvorada House

This research adopted a case study representative of a low-income housing typology, built in Porto Alegre, southern Brazil, which complies with most of those typical characteristics of a low-income Brazilian housing such as reduced area, rectangular shape on the plan, medium-sized windows, pitched roof and eaves. The case study is a north-south oriented one-storey detached house of a useful area of 38.67m^2 (Figure 1). The house accommodates externally two porches, used as a space of transition for the house access apart from its shading function.

However, differently from the other typical low-income housing typologies, this house was designed using passive design strategies with the aim of providing better environmental quality to its occupants at affordable costs. It was designed to be a place for investigation of passive design solutions applied to the context of compact affordable houses (Sattler, 2007). The house design considered a set of design strategies for increasing thermal comfort for both winter and summer periods. The strategies are described in Figure 1. Previous works on the Alvorada House can be found in Morello (2005), Grigoletti (2007) and Sattler (2007).

Furthermore, the house represents a degree of improvement in the current state-of-art of low-income housing typologies built in Brazil as it considers culturally accepted and high quality materials combined with the use of local and affordable techniques, instead of adopting a standardised strategy of the low-income buildings (Sattler, 2007, Tubelo, 2016).

The Alvorada House was constructed using uninsulated materials as traditionally found in southern Brazil. The walls were built out of a non-load-bearing masonry, mostly built out of a layer of solid bricks of 11 cm of thickness; small deviations of this pattern were considered for other wall facades and these are shown in Table 1. Windows were made out timber frame and single glazing (U-value: 5.78W/m^{2}K). Roof was designed mostly facing south to reduce the incidence of sun and was built out of ceramic roof tiles with a reflective aluminium foil inside to reduce the indoor heat transmission.

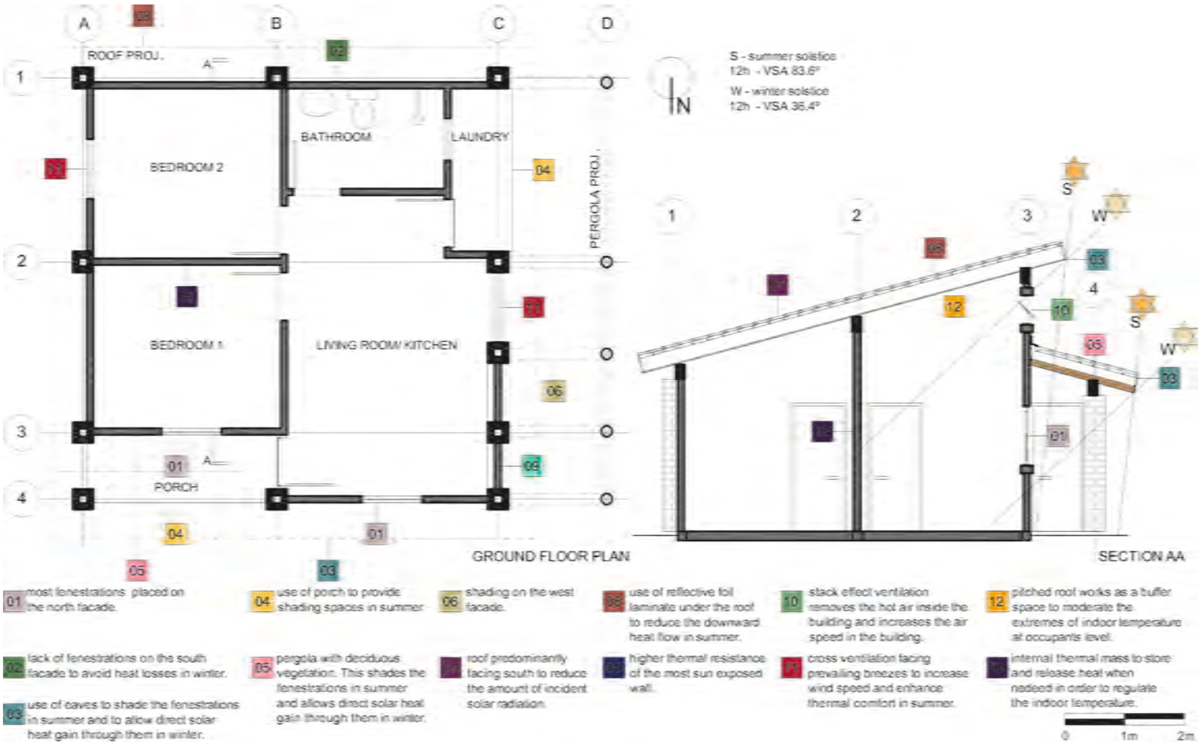
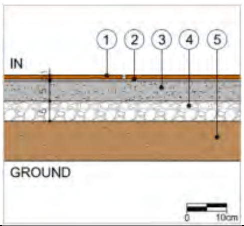
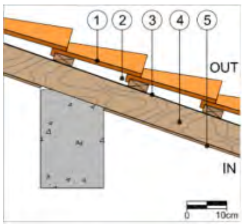
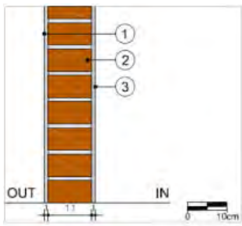
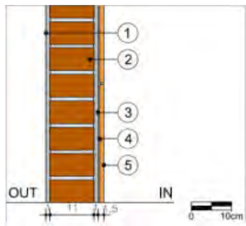
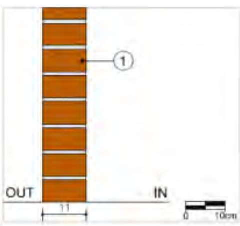
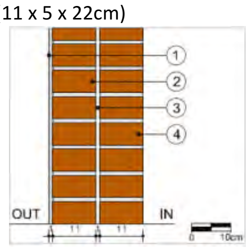
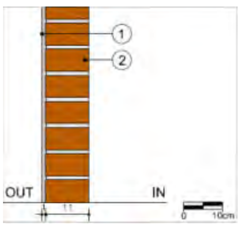
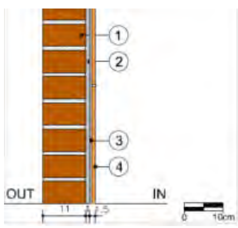


Figure 1. The Alvorada housing plan and section and the passive design strategies.

Table 1: The Alvorada fabric, as detailed in Sattler (2007) Morello (2005) and Grigoletti (2007)

Ground floor	**Roof**	**South walls**	
		(bedroom)	(bathroom)
U-value: 2.92W/m²K 1. 10mm Ceramic tile 2. 5mm Adhesive mortar for sticking ceramic tiles 3. 50mm Concrete slab 4. 50mm Stone chipping 5. Soil 	U-value: 0.98W/m²K 1. 10mm Roman clay roof tiles 2. Lathes 20 x 50mm; ventilation bet cross-lathing 3. 0.15mm Aluminium foil 4. Rafters 70 x 50mm; ventilation bet cross-rafters 5. 12mm Cedar lumber ceiling 	U-value: 3.36W/m²K 1. 10mm Lime cement plaster 2. 110mm Solid ceramic brick (11 x 5 x 22cm) 3. 10mm Lime cement plaster 	U-value: 3.23W/m²K 1. 10mm Lime cement plaster 2. 110mm Solid ceramic brick (11 x 5 x 22cm) 3. 10mm Lime cement plaster 4. 5mm Adhesive mortar 5. 10mm Ceramic tile 
North/east/west walls	**West walls**		
(bedrooms/living room/kitchen)	(living room/kitchen)	(living room/kitchen)	(bathroom)
U-value: 3.57W/m²K 1. 110mm Solid ceramic brick (11 x 5 x 22 cm) 	U-value: 1.82W/m²K 1. 10mm Lime cement plaster 2. 110mm Solid ceramic brick (11 x 5 x 22cm) 3. ~10mm air cavity (for building up) 4. 110mm Solid ceramic brick (11 x 5 x 22cm) 	U-value: 3.46W/m²K 1. 10mm Lime cement plaster 2. 110mm Solid ceramic brick (11 x 5 x 22cm) 	U-value: 3.32W/m²K 1. 110mm Solid ceramic brick (11 x 5 x 22cm) 2. 10mm Lime cement plaster 3. 5mm Adhesive mortar 4. 10mm Ceramic tile 

Unfortunately, the infiltration of the house is unknown as this type of test is not currently performed in Brazil. High infiltration impairs the thermal performance of the house and the delivery of the thermal comfort mainly in winter period as it allows uncontrollable air movement coming into the house mostly through its joints and leaky windows.

Porto Alegre Climate

Porto Alegre has a humid subtropical climate with a great seasonal and daily variation (Cfa according to Köppen climatic classification); the summers are hot with high levels of thermal humidity, while the winters frequently have colds and rainy days of a moderate amplitude but also have cold and sunny days of great temperature variation when under influence of polar waves (Tubelo, 2011). Average monthly temperatures and relative humidity are showed in Table 2. Annual average temperature is between 18 and 20°C (Alvares et al., 2014). Winter winds are mostly from south and southeast direction and are of low speed.

Table 2: Porto Alegre average monthly temperature (T) and relative humidity (RH), based on Roriz (2012)

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec
T (°C)	25.3	24.3	23.6	20.3	15.7	15.7	17.4	14.9	15.9	20.3	20.7	24.8
RH (%)	71	71	71	73	79	79	79	73	73	71	70	68

Methodology & Calibration

Envelope combinations were investigated using as reference the fabric first approach, replacing the current building envelope specification with an envelope with low thermal transmittance and infiltration values.

It should be noted that this house was chosen because a set of passive design strategies were already implemented. However, the concept of super-insulated envelopes was not considered and the authors saw it as one of the potential solutions to increase energy efficiency and comfort. Other potential design strategies were considered elsewhere (Tubelo, 2016) but were outside the scope of this paper.

The methodology consisted of the use of dynamic thermal building simulations using TAS (Thermal Analysis) software (EDSL, 2013), underpinned by 1-year of monitoring data collection obtained by Morello (2005). The use of empirical data helped to establish a realistic representation of the house. The monitored data did not include occupancy and so, the simulations allow for an estimate the house's potential post occupancy functioning.

Temperature data from monitoring was used to calibrate the simulation model. Literature to support the establishment of a good agreement between simulated and monitored data is not easily found. This research made use of ASHRAE (ASHRAE Guideline, 2002), that provides two different indexes. The mean bias error statistically measures how consistent the simulated data is related to the measured data and root mean square error statistically measures the magnitude of the varying quantity. The results corresponded to 0.7% and 5.6%, which were lower than the acceptable limits established by ASHRAE (ASHRAE Guideline, 2002) of 10% and 30% for hourly calibration data of the mean bias and root mean square errors, respectively. The referential used for calibration is showed in **Error! Not a valid bookmark self-reference.**.

The simulations analyses consisted of testing the house at different aspects: under the current condition that the house was built; under a degree of improvement compatible with highly insulated envelope, as those suggested by the fabric-first-approach-based regulations; and then, with a reduced infiltration rate.

Table 3: Calibration referential

Measured mean indoor temperature	20.86°C
Simulated mean indoor temperature	20.76°C
Standard deviation of measured indoor temperature	4.30
Standard deviation of simulated indoor temperature	3.85
Correlation coefficient	0.93
Mean Bias Error (< 10%)	0.7%
Root Mean Square Error (< 30%)	5.6%

The envelope optimisation was based on typical envelope construction elements adopted where saving-energy approaches have been used, as shown in IBO - Austrian Institute for Healthy and Ecological Building (2009) and in line with the Passivhaus standard referential of thermal transmittance of no more than $0.15W/m^2K$ for opaque elements (Passive House Institute, 2015). The selection of the optimised envelope was also based on a further study that investigated different envelope combinations varying each construction element at a time and this can be found in Tubelo (2016). The optimised envelope and its thermal property are shown in Table 4. The use of traditional materials was kept and high levels of insulation material were adopted. Windows of $1.42W/m^2K$ with low-e double glazing were used.

Standard infiltration referential for simulating Brazilian constructions is suggested to be 1 ach at atmospheric pressure, according to the NBR 15575 (ABNT, 2013). In the case of the reduction of the infiltration, as buildings in Brazil are mostly naturally ventilated, especially those used for low-income householders, minimum requirement of infiltration for maintaining the use of natural ventilation was adopted. The referential used in the United Kingdom regulation of $3m^3/hr/m^2$ at 50 Pa in which no additional mechanical ventilation system is required was adopted (Cotterel and Dadeby, 2012, NHBC Foundation, 2009). This is calculated to be roughly equivalent to 0.15ach.

Each room of the house was considered as a thermal zone and specific patterns of use were adopted accordingly. The occupancy pattern aimed to simulate as close as possible the real condition of use (Table 5). Household appliances considered the most typical ones found in Brazilian residential buildings. Lighting power and usage were based on INMETRO (2012).

The results obtained from the dynamic thermal simulation were compared in terms of thermal comfort and energy expenditure. Internal doors were kept opened in the simulations and because the results for the rooms were quite similar due to the small size of the house, data from the living room were used as representative.

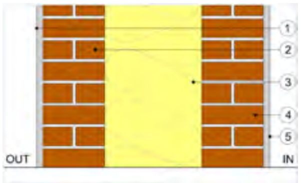
As for the energy calculations, the building can operate in mixed mode, a more conservative criterion of thermal comfort was adopted to be between 20-25°C. However, the occupants of residential buildings can tolerate a wider range of temperatures (Nicol et al., 2012) and because of this adaptation, a wide thermal comfort interval of 18-29°C was also considered in the analyses. The choice for the wide comfort limit considered the adaptive approach in which the temperature intervals were calculated according to ANSI/ASHRAE Standard 55 (2010). The calculated comfort limits for Porto Alegre corroborate with the referential suggested by Givoni (1992) of 18-29°C of temperature to be used in Brazil.

The cost analyses explored the viability of the envelope optimisation and they were undertaken using the TCPO database (PINI, 2015b), which is a Brazilian database with more than 5 thousand typical construction composition prices (PINI, 2015a). The cost analyses compared the costs of the main house envelope elements as built against the costs of the optimised envelope.

Table 4: Optimised envelope construction.

Wall

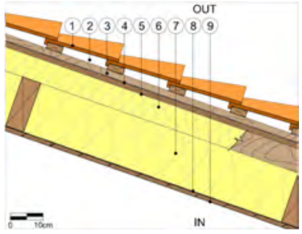
U-value: 0.11 W/m^{2}K



1. 20mm cement plaster
2. 190mm solid ceramic brick 300mm EPS
3. 190mm solid ceramic brick
4. 20mm cement plaster

Roof

U-value: 0.15 W/m^{2}K



1. 10mm clay roof tiles
2. Lathes 20x50mm
3. Lathes 20x50mm
4. Open diffusion sheet
5. 16mm wood fibre
6. 70mm mineral wool panels bet. cross-rafters
7. 160mm mineral wool panels bet. horiz.-lathes
8. Vapour barrier
9. 12mm timber ceiling

Table 5: Simulation assumptions

Occupancy	2 people per bedroom at rest for a use schedule of 10 hours in weekdays and 12 hours in weekend; all occupants in the living room at sedentary work with an occupancy of 5 hours in weekdays and 10 hours in weekends.
Lighting	5W/m^2 for bedrooms, usage 3 hours per day; 6W/m^2 for the living room; usage 5 hours per day in weekdays and 6 hours per day in weekends.
Household appliances	TV of 30W used 4 hours per day; Fridge, microwave, iron and washer were assumed at a typical usage, totalling a daily energy consumption of 1.9kWh.

Results

Thermal comfort analyses

Externally, the temperatures were mostly within the thermal comfort; 36.7% of the time they were below 18°C and 6% of the time they were above 29°C. The occupied areas were within the thermal comfort of 20-25 °C and 18-29 °C for 42% and for more than 81% for the current envelope condition, respectively (Table 6).

The adoption of the insulated envelope increased the thermal comfort in the occupied areas by 73% and 21% for the narrow and wide thermal comfort interval when compared to the current envelope, respectively. The occupied areas were within the thermal comfort of 20-25 °C and 18-29 °C for more than 72.5% and for 98% of the time, respectively. The main change was related to the reduction of thermal discomfort for temperatures below 20°C and above 25°C.

The adoption of an insulated and airtight envelope diminished the thermal discomfort to negligible levels. The occupied areas were within the thermal comfort of 20-25°C and 18-29°C for 96.8% and 100% of the time, respectively. This meant an increase of the narrow and the wide thermal comfort by more than 33% and 2% when compared to the case of only the change of the envelope but at a standard infiltration rate; and it represented an improvement of the thermal comfort of 130% and 23% related to the current envelope, respectively.

The occupied areas of the Alvorada House had a peak temperature of 32.82°C in the living room/kitchen in the current envelope use. Adopting the insulated envelope at a standard infiltration rate, the indoor peak temperature was reduced by about 5.5 K relative to the current condition. Using the insulated and airtight envelope, the indoor peak temperature was 1.5 K lower than in the insulated envelope at a standard infiltration rate and about 7K lower than the current envelope use.

Table 6: Thermal comfort levels

°C	Ext.	As built	insulated envelope + 1ach	insulated envelope + 0.15ach
20-25	30.8%	42.0%	72.5%; 73% more related to as built.	96.8%; 130% more related to as built.
18-29	57.2%	81.0%	98.0%; 21% more related to as built.	100%; 23% more related to as built.

Energy efficiency analyses

The Alvorada House envelope as built had its annual energy demand estimated to be 45.39kWh/m^2. With the adoption of the insulated envelope at a standard infiltration rate, the energy demand would be reduced to 5.35kWh/m^2. Then, with the reduction of infiltration, the energy demand would be smaller than 1kWh/m^2. This meant that the optimisation of the envelope and later the reduction of infiltration levels would be able to achieve annual energy savings of 88.21% and 99.3% compared to the Alvorada House envelope as built, respectively.

For a 50-year lifespan period and considering the average Brazilian inflation on the energy tariffs, the costs for running the Alvorada House as built would be 8.5 times bigger than the situation with an optimised envelope at standard infiltration and 151.3 times bigger with the scenario of the optimised and airtight envelope if a mixed mode scenario would be adopted to maintain the temperatures within the thermal comfort interval of 20-25°C.

However, the costs of the optimised envelope showed to be 4.1 times more than the costs of the Alvorada House envelope as built. A cross-analysis of the costs of the envelope and costs for running the housing (for a standard infiltration rate of 1 ach) revealed that the payback period would be estimated to be approximately 19 years. The envelope optimisation would add 65% to the overall typical Alvorada House cost. The analysis could not estimate the cost for building an airtight envelope as it might require a great effort of all construction actors in both design and construction stages (Pacheco, 2013, Tubelo, 2016).

Final considerations

This paper looked at increasing the thermal performance of a low-income housing, built in southern Brazil, by acting on its envelope. The work adopted insulated and airtight building envelope as response for the delivery of energy efficient and thermally comfortable houses.

The results showed that the optimised envelope adopted would be able to deliver up to 130% more thermal comfort and up to 99% more energy savings in comparison to the envelope as built. However, the findings demonstrated that the overall housing costs would be exceeded in more than 65% compared with its typical costs, which makes the optimisation unfeasible for these income range households and house typology.

It remains a scope for investigation the accurate quantification of the levels of infiltration adopted in Brazil and its potential thermal comfort benefits in case of reduction. It is also important to investigate the potential cost increase of the reduction of infiltration in order to explore its feasibility in the Brazilian housing construction.

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Passive Design with Affordances: Natural Ventilation and Adaptive Shading for Comfort, Churachandpur

Khuplianlam Tungnung[1], Yuichiro Kodama[2], Arvind Krishan[3] and Koji Takemasa[4]

[1] Department of Planning and Architecture, Asst Prof., National Institute of Technology (NIT), Rourkela, India, tungnung.khuplianlam@yahoo.com;
[2]ESTEC Design, Prof. Emeritus, Kobe Design University, Japan, kodama@estec.jp;
[3]CASA (Center for Architectural Systems Alternatives), Principal Architect CASA, Prof. Emeritus, AMITY University, Noida, India, arvindkrishan@gmail.com; LEAD
[4](Low Energy Architecture and Design) Labo, Hiroshima, Japan, koji.takemasa@gmail.com

Abstract: Humans and most organisms require varying degrees of porosity in their natural way of life, and traditional designs exemplify porosity as essential parameter to comfort and functionality. Based on the theory of affordance, complementarity of climate and lifestyles, the paper highlights the pertinence of passive design: adaptive shading, ventilation (summer) and air-tightness with glazing (winter). Adaptive wooden louvers on the West (vertical) and South (horizontal), and shading protects the indoor environment from overheating in summer while allowing solar heat gain in winter. Low thermal conductivity materials and natural ventilation through space syntax integration between private, semi-private, public zones or indoor and outdoor could be conducive for comfort. The objective is to highlight low-energy passive design strategies through the analysis of passive climate charts and parametric simulations and further respond to local needs: vernacular reinterpretation, economic, and environmental symbiosis. Comfort parameters are temperature (℃), relative humidity (%), and air-velocity (m/s). PMV's range of -1 to +1, comfortable, is possible on most days through affordance: complementarity of climate and lifestyles in passive architectural niche which are expected to be novel strategic principles towards designing to thrive in an increasingly energy intensive built environment.

Keywords: Affordance, passive design, climate, parametric, comfort.

Introduction

Humans and most organisms require varying degrees of porosity to thrive and grow in their natural way of life, and traditional designs that have been an integral part of Manipur's environment and daily way of life also exemplify porosity as essential parameter to comfort and efficient function. E.g., Matted split bamboo baskets, wood or bamboo and thatch houses, etc. As concomitants to eccentric development and lifestyle changes, energy consumption in the form of electricity or gas increases since traditional passive ideas were substituted by active cooling or heating and comfort is often limited to high energy heat sources in winter or fans and air-conditions in summer. The design of this propose porosity house envelope and planning affords possibilities for low-energy comfort through various degrees of porosity: natural ventilation (summer) and air-tightness (winter) in combination with adaptive shading and other passive design techniques. As a theoretical basis, 'affordance' (Gibson, 1979) connotes the complementarity of the architectural niche ingenuity, climate and proactive lifestyles responsive to diurnal or seasonal changes while paying homage to the vulnerable vernacular habitats. In the last few decades, the lifestyle of most families in Churachandpur have changed due to interstate or international travel or habitation, employment, merchandising, and access to internet and print media, etc. Concrete and steel materials, auto-centric and high-energy developments without appropriate passive design principles radically changes the traditional means to affording comfort associated with vernacular dwellings. Often, local resources: materials, energy, infrastructures, and local architectural paradigms are at odds with the new paradigm shifts. The basic traditional tenets of proactive lifestyles, natural ventilations with envelopes' porosity, low thermal conductivity material paradigms have been sacrifice to development.

Hypothesis, Objectives and Methodology

Architectural reinterpretation of novel traditional ideas and revival of proactive lifestyles proposed in this modern porosity house aims to highlight the pertinence of porosity: natural ventilation, and adaptive shading in cool-humid areas of Manipur. The hypothesis is base on the theory of affordance: complementarity of the building's adaptive envelope with the users' lifestyles, and connectivity of indoor and outdoor for good ventilation, appropriate air change rates (ACR). These could afford comfort in indoor thermal environment. Space syntax layout of kitchen, dining, living, stairs, bedrooms, lounge, attic space, etc., facilitates natural ventilation. The primary objective is to established novel passive design principles and strategies for comfort with low-energy through vernacular reinterpretations, computer simulations, and responsive lifestyles. Qualitative site survey was done and quantitative systematic computer simulations for various grades of ventilation, air change rate (ACR), and adaptive shading were perform in combination with other optimal passive design techniques in Solar Designer Ver.6.0. Pertinent findings in summer and winter are expected to highlight a more resilient low-energy built environment possibilities. Predicted indoor temperature and relative humidity were analyzed with CBE's thermal comfort tool and indoor thermal comfort possibilities were studied under various adaptive activities, air change rate (ACR), and clothing.

Survey and Analysis

Macro Climate Analysis

Hill-town Churachandpur is located near Imphal at coordinates: 24°20’N 93°41’E at an elevation of 914m above MSL. Spring and autumn are pleasant while winter can be damp and cold without adequate sun penetration; summer is hot without appropriate shading and ventilations. Figure 1 shows the mean temperature fluctuation ranges: 14-18°C in winter and 6°C in summer. The mean diurnal temperature high is about 20°C or more through the year. Diurnal maximum is 28°C or more but drops to about 20°C at night in summer, and minimum is 6°C or less in winter nights. Maximum solar radiation is 500W/m² or more throughout the year. The nights’ humidity ranges 80-95% or more and diurnal humidity is 70% or less through the year. Wind speed is 0.4-3.4m/s in the day, and the nights are calm, 0-0.2m/s through the year. Prevailing wind direction is from West in February-May, and S-East in June-December. Figure 2 shows the project site location near the foothill of a mountain in a mid density residential area with detached houses, mixed used shops, and cultural buildings. In summer, the temperature variations between the hills and the residential areas could modify micro-climate due to cool breeze from the hills to the relatively hotter residential areas.

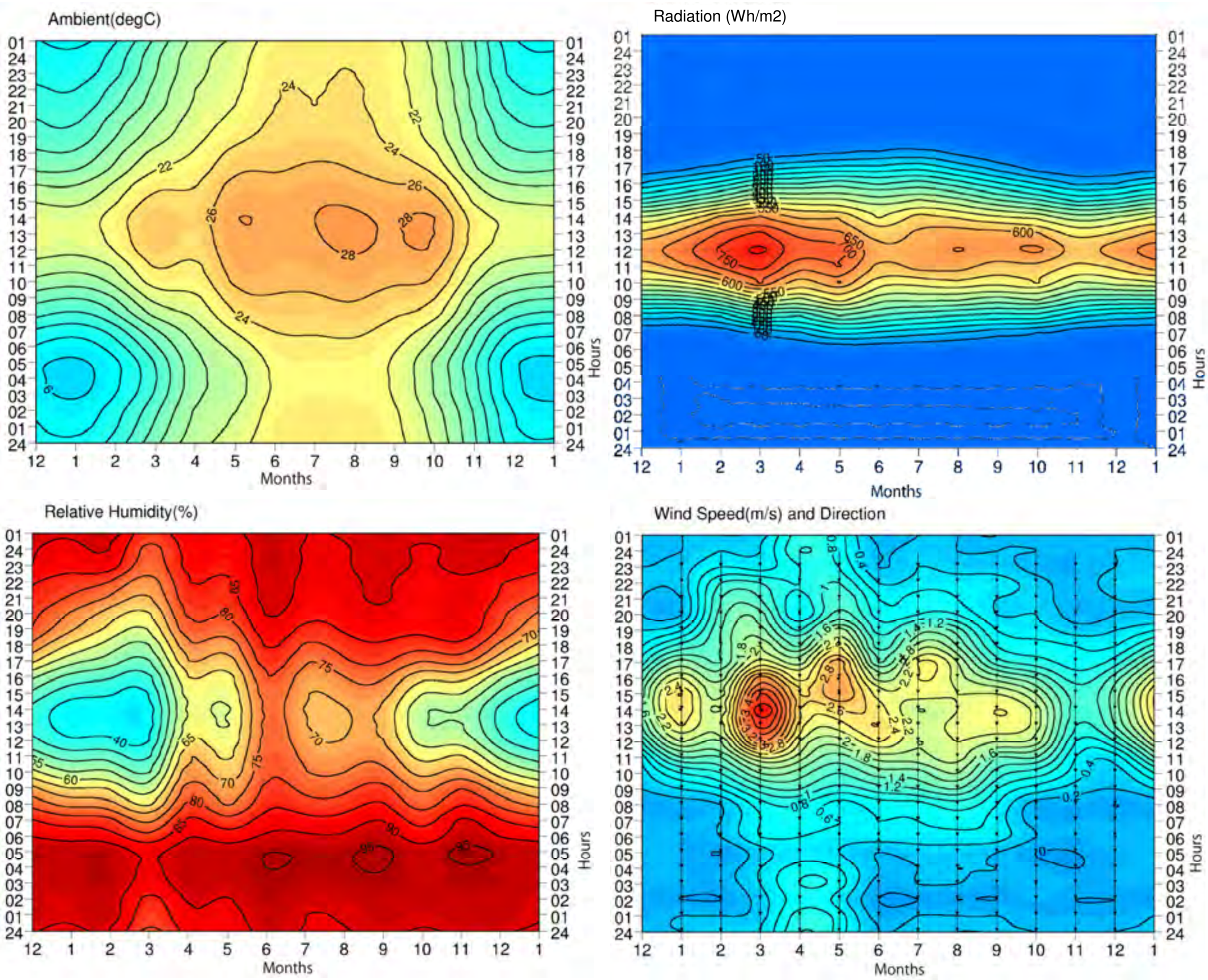

Figure 1: Passive climate charts' climate parameters fluctuation in cool-humid Imphal, near Churachandpur.

Space and Function

Space and Function in Vernacular Architecture

Figure 2: Site view showing mid density detached houses from surrounding hills, in Churachandpur.

Figure 3: Vernacular habitats extroverted space functions, and porosity of envelopes with deep thatch eaves.

Generally, a house functions as an evening and night-time occupancy in traditional dwellings due to agricultural occupation for working members, except for children and the elderly who stays home. While the absence of high industrial development is noted in the vernacular habitats, it doesn't necessarily mean low technical soundness or inadaptability for modern reinterpretation towards climatic responsiveness and proactive low-energy lifestyles. "As concomitants to the cool-humid climatic parameters, resources and socio-cultural praxis, the vernacular habitats are one-room typologies that afforded inherent flexibility to fulfil multiple functions: dining or living, bed or lounge, social gatherings, and workspaces for cooking, weaving traditional shawls or bamboo. The front veranda performs a versatile function of workspace, rainwater harvesting from thatch roof, and social space or enjoy fresh air. People's culture and lifestyles has made adaptations as a response to basic human body's comfort needs by wearing warmth clothes in winter and lighter porous cotton clothes in summer." (Tungnung, 2015). Figure 3 shows possible passive design lessons: space syntax of the vernacular habitats indoor and outdoor, envelope's porosity, and deep thatch eaves that afforded ventilation and shading, as well as complementarity of lifestyles in the use of indoor and outdoor, depending on the time and seasons.

Selection of Appropriate Passive Design Techniques and Paradigms

Manipur's cool-humid climate necessitates heating in winter and cooling in summer. In vernacular habitats, "porosity: air-flow, light and shade due to low thermal conductivity porous envelope and void like interiors with attic space afforded protection to the living-dining hall from the sun while ensuring seamless connectivity of the interior and exterior for airflow and the same attribute allows control radiation of heat or glare-free diffuse light from the sun or fire-place, evenly, to all parts of the house." (Tungnung et al, 2015). Modern reinterpretation possibilities and appropriate passive design paradigm were selected by simulating a module with different envelope materials: 'A', adaptive wooden louver and glazing on four walls; 'B', light weight wood on the East and West and louvers with glazing on north and south; and 'C' is a high mass 230 brick wall with openings on North and South. Figure 4a shows maximum temperature ranges for module 'A' in winter due to air-tightness, indoor heat sources, earth contact plinth, night curtains, etc. Module 'B' shows high fluctuation while 'C' is stable but low. In figure 4b, 'B' and 'C' under night-ventilation shows higher diurnal temperature due to small temperature fluctuation on cloudy & sunny days. Low nighttimes' ACR and indoor heat can increase diurnal temperature in low mass 'B' and high mass 'C'. Higher ACR may not be possible in 'B' and 'C' due to small openings and low wind speed. But 'A' has adaptive porosity and higher ACR is probable and shows low temperature ranges due to higher ACR and low ambient temperature except on peak very sunny days. Given the novelty concerns of reinterpreting vernacular passive techniques, 'A' was chosen as a possible appropriate architecture with adaptation for winter comfort needs using glazing. Some peak summer days are hot, but when it's cloudy or rainy the weather can be pleasant. The indoor temperature can be modify by opening or closing glazing.

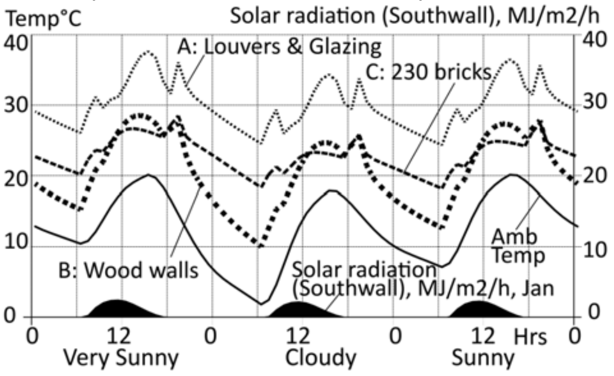

Figure 4a: Temperature fluctuation in Modules A, B, C under low ACR of 0.5, day & night, January.

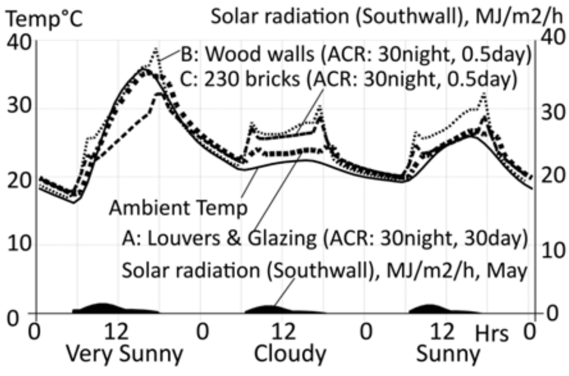

Figure 4b: Temperature fluctuation in Modules A, B, C under probable air change rates (ACR), May.

Space and Function in Re-interpreted Modern Architecture

The paper investigates reinterpretation possibilities of traditional porosity design in the form of adaptive envelope elements: wood louver walls and glazing windows, and adaptive shading to respond to seasonal changes in the context of an increasingly energy intensive housing and lifestyle paradigms. Figure 5 shows image of high porosity envelope with cool-air inlet at the ground while the stairs, porous wood floor, and attic space serves as hot-air outlet and buffer. The semi-public living-dining, kitchen, and verandas have good horizontal spatial syntax integration, while the stairway ensure good vertical space syntax integration for air-flow and connectivity. Adaptive porous louvers and glazing on the hill facing facades: West and South allows natural ventilation and cool hill breeze due to micro-climate effects of cooler hills and hotter residential areas in summer and green-house effect in winter. The front courtyard could serve as heat sink to the building. The *verandas* reminisce traditional space syntax integration of indoor and outdoor functionally for working as well as social space. The use of corrugated metal sheets without insulation on the roof resulted in hot attic-like spaces for the top floor due to high thermal conductivity and high emissivity, but the same thermal principles could afford for a cool space in the evening and nights. As a response to such pragmatic issues: thermal environment in the day and night and social privacy needs, the bedrooms and private lounge are propose at the top floor and the semi-public living-dining-kitchen room in the ground floor for daytime use. The living-dining room in the ground floor affords an appropriate thermal environment for occupants comfort in the daytime with shade, buffer space of the attic-like first floor, and porosity of the walls that allows space syntax integration with the outdoors. These passive design techniques are expected to be pertinent to thermal comfort without air-conditioning or with minimal use of fans. Verandas on the mountainside serve as thermal buffer and semi-outdoor spaces to enjoy cool breeze and view sunsets.

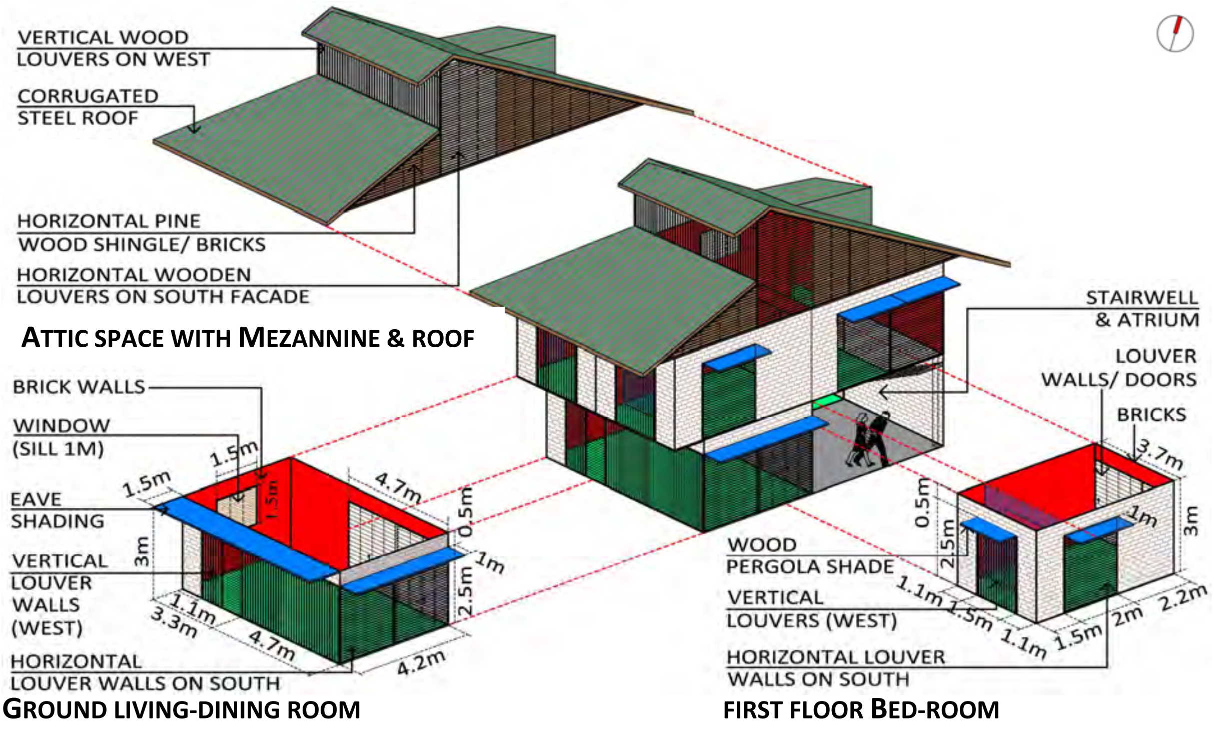

Figure 5: Modern reinterpretation of vernacular indoor-outdoor space syntax integration to account for ventilation in the private (bedroom, attic), semi-private (living-dining) and public spaces (stairs and veranda).

Parametric Simulations for Selection of Optimal Passive Design Techniques

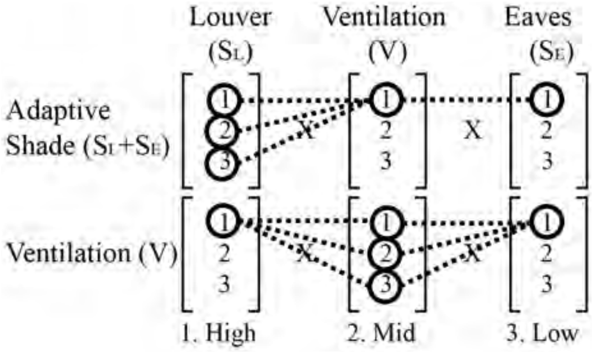

Figure 6a: Simulation combinations for selection of optimal passive design techniques in summer.

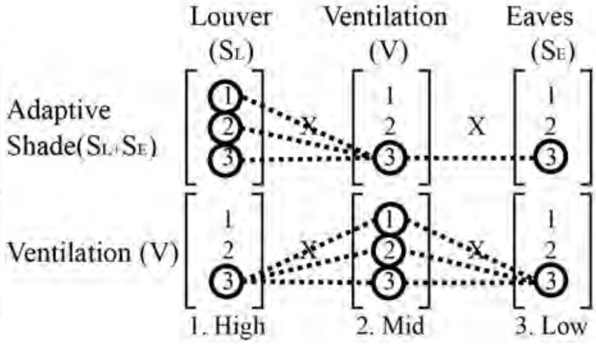

Figure 6b: Simulation combinations for selection of optimal passive design techniques in winter.

Spaces thermal performance is affected by various parameters: ventilation, thermal mass, shading, etc. Figure 5 shows the module analyze, ground living-dining with wood louvers and minimal brick walls, earth contact plinth, and insulating buffer first floor. The lifestyles of the 6 family members and room occupancies, internal heat generations, etc., are simulated in the best representative way for summer and winter. Adaptive shading can be achieved by controlling solar transmittance, sash ratio, with operable louvers (S_L) and awnings or eaves (S_E). For simulation of passive design's optimal combination, the optimal grades were selected and only the parameters of the passive technique analyze is systematically varied. To analyze the effects of shading with louvers (S_L), the other invariant combinations of Ventilation (V) and shading with eaves (S_E) are: 1, high grade in summer and 3, low grade in winter. The same system is applied for shading with eaves (S_E), and ventilation (V). Louver (S_L) grades: 1). 85%, 2). 50%, 3). 15% were systematically varied by changing the window sash ratio. For ventilation, the grades are: 1). V1, All-day-ventilation (30acr, day & night), 2). V2, night-ventilation (30acr night, 0.5acr day) in summer, and day-ventilation (0.5acr night, 30acr day) in winter, 3). V3, air-tightness (0.5acr, day and night). The grades of shading with eaves (S_E) are: 1). High (Adaptive), 2). Mid, 3). Low.

Ground Floor Living-dining

Churachandpur has moderate temperature fluctuation ranges in winter, but low in summer. So, thermal storage and the effect of stabilizing the room temperature fluctuation is not envisaged in summer and low mass module is selected. In winter, solar heat gain through large glazing areas and air-tightness can be beneficial.

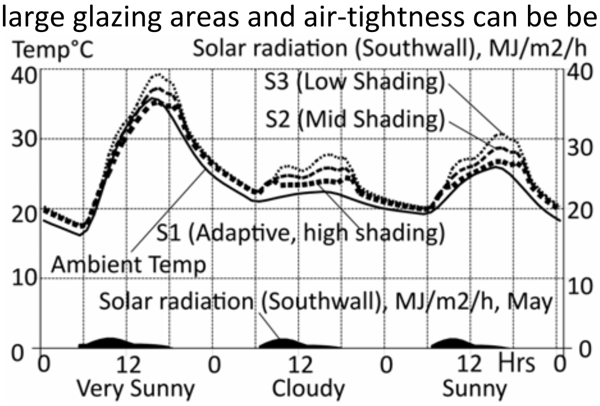

Figure 7a: Temperature fluctuation due to the effects of various shading grades on 3 typical summer days.

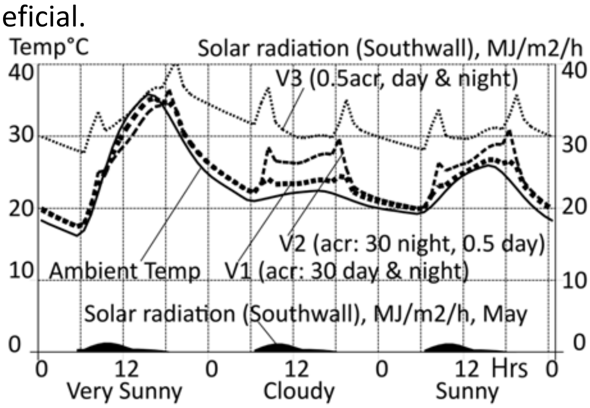

Figure 7b: Temperature fluctuation due to the effects of ventilation modes on 3 typical summer days.

Figure 7a shows the effects of shading (S): eaves (S_E) and louver (S_L) walls on the indoor thermal environment in the ground living-dining room under all-day ventilation with

30ACR, day and night, for May. The effects due to various shading (S) grades: S1). Adaptive (high); S2). Mid; S3). Low shows significant diurnal temperature fluctuation ranges. Since the module is under all-day ventilation with low mass and low thermal conductivity, the effects of materials cool storage are negligible. The outdoor temperature and RH (%) are relatively lower than inside, so the idea is to dissipate indoor heat gain and humidity from equipments, people, and wet areas such as, kitchen, toilets, etc. On peak summer days, when the temperature is above comfort ranges (30°C) adaptive comfort is expected to be possible through natural ventilation, adaptive lifestyles, and fans. Figure 7b shows predictions for the same living-dining room under different ventilation modes: V1, high; V2, mid; and V3, low. The use of high heat generating equipments, in the morning and evening, increases indoor temperature. In spite of the low mass, direct solar heat gain through the large glazing areas resulted in high indoor temperature ranges due to air-tightness for V3. Night-ventilation (V2) and all-day ventilation (V1) shows comfortable indoor temperature ranges except on very sunny peak summer days. Figure 8a shows the effects of shading (S) with eaves (S_E) and louver (S_L) for the ground floor living-dining room under air-tight ventilation with 0.5ACR, day and night, for winter. The effects on the room temperature fluctuations due to the difference of various shading grades: S1, S2, and S3 show significant temperature fluctuations. Even though the module has low thermal mass, air-tightness (0.5ACR) affords comfortable temperature ranges even in the night. S2 and S3 are lower than S1, and the ambient temperature is much lower, since adaptive shading (S1) affords direct heat gain and indoor heat sources also increases temperature. The ambient temperature is cold, so the idea is to reduce heat transfer from indoor to outdoor at night and retain solar heat gain and indoor heat with air-tightness. When the temperature is above comfort ranges, >30°C, natural ventilation can dissipate heat. Figure 8b shows prediction results of the room under different ventilation modes: V1, V2, V3. In spite of low thermal mass, temperature ranges are high for V3 throughout day and night due to air-tightness, solar heat gain from large glazing areas, and indoor heat generation. All-day ventilation shows low temperature ranges in cold nights. Unlike regions with high diurnal winter temperature, day ventilation with high ACR in the daytime and low ACR in the night shows low temperature ranges in the morning due to low ambient temperature ranges.

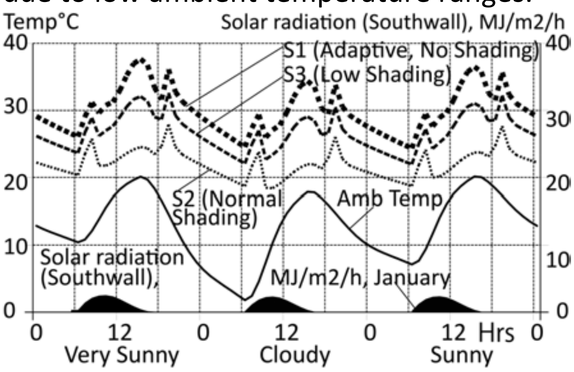

Figure 8a: Temperature fluctuation due to the effects of shading grades on 3 typical winter days.

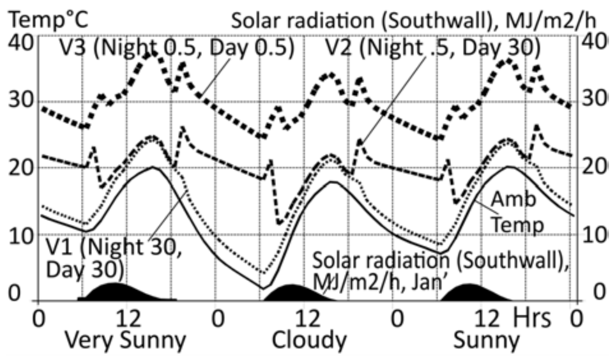

Figure 8b: Temperature fluctuation due to the effects of various ventilation modes on 3 typical winter days.

Indoor Comfort Analysis

Analysis on thermal comfort accounts for the effects of radiation from the envelopes and indoor air temperature by considering operative temperature, OT. Relative humidity was calculated with psychrometric chart and CBE thermal comfort tool was used to calculate PMV for normal as well as adaptive clothing, air-velocity, and activity (Met rate).

Without adaptive comfort, PMV (Predicted Mean Vote) fluctuation under calm air-velocity (0.2m/s) and summer clothing (0.5clo) for 3 typical days of May shows thermal sensation of > +2 (hot) to -3 (vey cold) depending on the time of the day. However, with adaptive comfort through adaptive air-velocity, activity, and clothing, PMV shows thermal sensations of -1 (Slightly Cool) to +1 (Slightly Warm) except on peak hot and sunny days.

Conclusions

Low-energy passive design base on the theory of affordances: complementarity of climate, lifestyle and ingenuity of architecture was attempted through reinterpretation of traditional design principles', porosity with low mass and low thermal conductivity materials, in modern context for natural ventilation (summer), and adaptive shading and glazing were added for heating and cooling synergy needs. Low thermal conductivity porous envelopes, space syntax integration between indoor and outdoor were essential to natural ventilation needs, and parametric simulations shows appropriate ventilation, adaptive shading and glazing complements the needs of vernacular reinterpretation, economic, and environmental symbiosis. As a passive design principle based on the theory of affordance: complementarity of lifestyle and climate, adaptive clothing, activities and air-velocity shows PMV's range of -1 to +1, comfortable, except on peak summer days with explicit links to low-energy possibilities. The porosity proposal is expected to serve as cue to reduce energy consumptions, proactive lifestyles, user-initiated incremental adaptations towards comfort, freshness and enhance quality of life. The paper, through the analysis of design tools: passive climate charts and parametric simulations, validates the applicability of local affordances: complementarity of climate and lifestyles, vernacular reinterpretations and shows novel principles towards designing to thrive in a rapidly changing built environment in cool-humid Manipur.

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People's Behaviour in Choosing Optimal Thermal Places for Sustainable Lifestyle: Reducing Air-Conditioning Use in Tropical Climates

Tomoko Uno[1], Sri Nastiti N. Ekasiwi[2] and Tetsu Kubota[3]

[1] Department of Architecture, School of Human Environmental Sciences, Mukogawa Women's University, Nishinomiya, Japan, uno_tomo@mukogawa-u.ac.jp;
[2] Department of Architecture, Faculty of Civil Engineering and Planning, Institute Technology Sepuluh Nopember Surabaya, Surabaya, Indonesia, nastiti@arch.its.ac.id;
[3] Graduate School for International Development and Cooperation, Hiroshima University, Hiroshima, Japan, tetsu@hiroshima-u.ac.jp

Abstract: In humid tropical climates, the passive behaviour of residents contributes to the reduction in energy consumption in the same way as passive designs contribute to energy saving. We measured the thermal environment in Surabaya, Indonesia, and conducted interviews with its residents to determine which rooms and terraces they freely select as their ideal environment. The results showed that the residents change locations on the basis of what they think are comfortable environments in the house at different times of the day; for example, they stay on the 1st-floor northern terrace in the morning and the 2nd-floor southern terrace in the evening. On the 1st-floor northern terrace, the temperature does not increase in the morning because of the shade and large thermal mass of its concrete floors and increases at noon because of the reflection of solar radiation. In the evening, the temperature of the 2nd-floor southern terrace drops more quickly and below that of the 1st-floor northern terrace because of higher winds. Thus, the thermal environments in selected locations in the house are more comfortable than in other locations. Choosing a comfortable location in the house reduces residents' use of air conditioning and contributes to energy saving.

Keywords: Selection of ideal environment, resident's behaviour, field survey, hot and humid climate

Introduction

In Indonesia, population increase along with the recent economic growth has led to the expansion of cramped houses, which lead to no spaces between buildings or houses or in houses, in urban areas. The semi-open spaces that Indonesians used as common spaces are decreasing in these houses, which tend to be cramped and closed to the outside (Alfata et al., 2015). These houses are easily affected by outdoor conditions, and residents of such houses control the indoor thermal environment using air conditioners. Nowadays, household energy consumption is rapidly increasing in Indonesia (BPS, 2014), along with the increasing use of air conditioners to achieve comfortable thermal conditions.

According to the results of the field surveys conducted on the thermal environment in houses with air conditioners, people prefer using air conditioners for longer hours at lower temperature settings especially while sleeping (Ekasiwi et al., 2014; Uno et al., 2003a). Furthermore, houses with a very low thermal performance are not effective for air conditioning (Uno et al., 2012). The way in which the air conditioner is used can cause serious problems for both energy consumption and resident's health.

Passive design, which is an architectural design to realize low energy without air conditioners, contributes further to these problems. However, in cramped houses in crowded cities, these passive designs tend to be ignored for economic efficiency. It is actually vital to consider passive designs appropriate for the local climate. Additionally, residents' behaviour in moving around the house to choose the ideal thermal locations is also important (Gusti & Ekasiwi, 2006). Using field surveys on and measurements of thermal environments, this study evaluated this behaviour of residents from the viewpoint of their thermal preferences.

Survey area and measurement season

The surveyed area is in Surabaya (7°S 133°E), which is located in the eastern part of Java Island in Indonesia. It is located in a hot and humid climate, with 2 predominant seasons: dry and wet. There is little precipitation during the dry season from May to October. The annual mean temperature is 28°C, and the monthly average temperatures vary from 27.2°C to 29°C (Figure 1). The average monthly relative humidity is between 65% and 80%.

The measurements and field surveys were conducted between August 31 and September 2, 2016, during the dry and slightly hot season. Figure 2 shows the results of the outdoor temperature, relative humidity and solar radiation measured in the courtyard of the target house. The outdoor temperature rose to 35.5°C. The surrounding wall shades the house from solar radiation before 09:30 and after 15:30. The estimated solar radiation shown in Figure 2 is the integrated value of the direct and diffused solar radiation estimated through Berlage's and Bouguer's equations (Hokoi et al., 2002), respectively, at an atmospheric transmissivity of 0.7 [−].

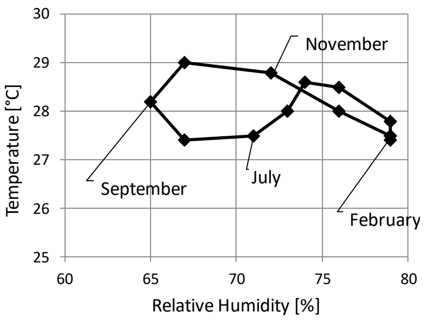


Figure 1. Temperature and relative humidity in Surabaya.

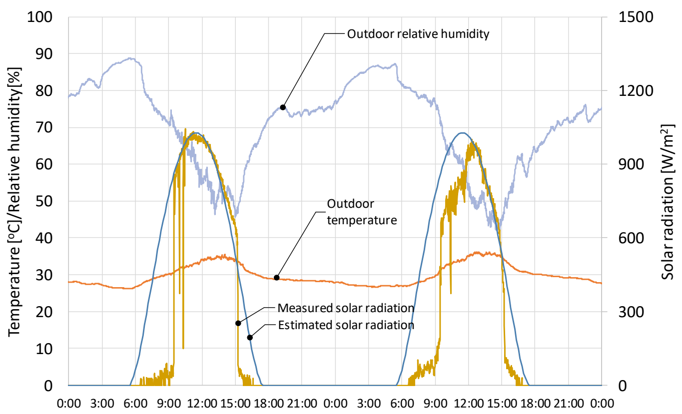


Figure 2. Measured outdoor temperature, outdoor relative humidity, and solar radiation.

Plan of measured house

The target house is located in the urban area of Surabaya City. Two people (80-year old man and 77-year-old woman[Note1]) live in the house; the man works in the university laboratory, and the woman stays in the house all day long. The man designed the basic concept of the house, which was aimed at reducing the number of partition walls to make the space open and easier to accommodate visitors and to integrate the greenery surrounding the house.

The house is detached and shares the eastern, western and northern walls with the neighbours. There are 6 rooms, 2 halls, 3 terraces and a courtyard on the north side of the house (Figure 3). The dining space is open to the south-side garage and to the north-side courtyard. Every room has small openings connecting to the outside (Figure 4a, b). The main structure is reinforced-concrete (RC) with brick walls and the wooden roof with aluminium film and insulations.

Resident's behaviour and thermal sensation in each space

Table 1 shows the schedule of the locations in which the residents stay throughout the day.

The dining/kitchen space (Figure 4c) is used during mealtimes in the morning and in the evening. Because the space is well ventilated and wind flows frequently, the residents feel slightly cool, neutral or slightly warm. On calm days, they sometimes use an electric fan all day. When they feel uncomfortable in the dining/kitchen space, they move to the bedroom on the first floor.

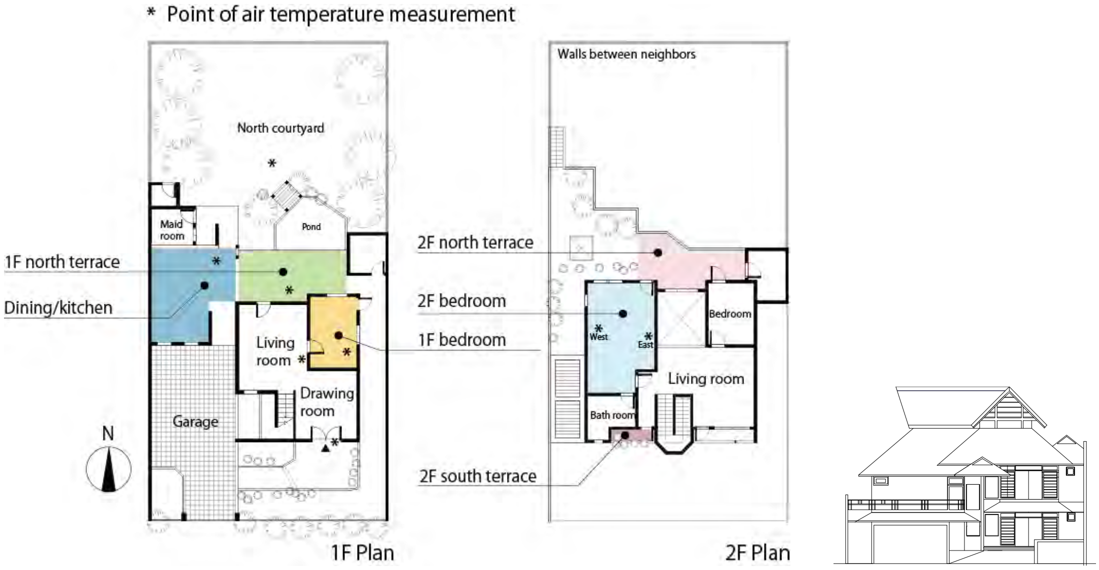


Figure 3. 1st- and 2nd-floor plans (left and middle) and south facade (right) of the house.

Figure 4. Inside of the house (a: 1F northern terrace, b: 2F bedroom, c:1F northern terrace and dining/kitchen, d: 2F southern terrace).

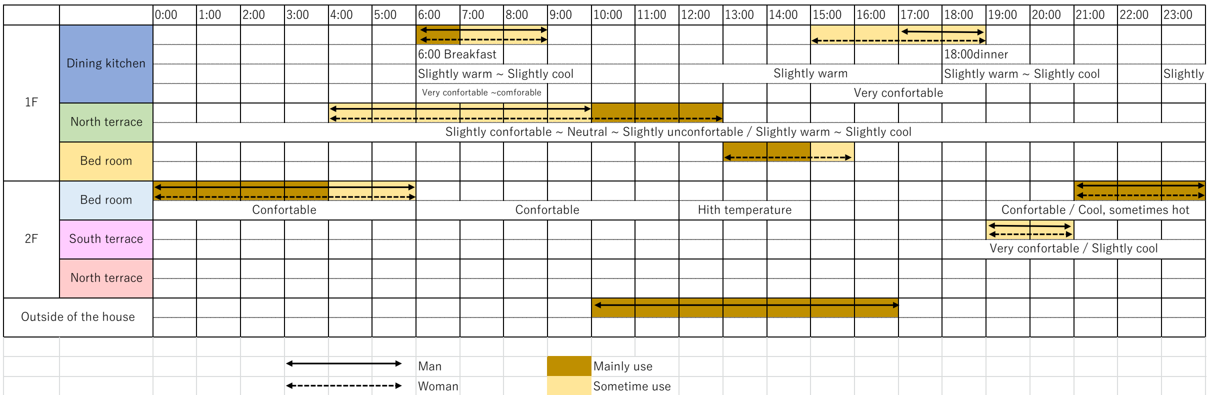
The wife stays on the northern terrace on the first floor as well as in the dining/kitchen space in the morning. Both of them describe the space as slightly comfortable, neutral or slightly uncomfortable.

The southern terrace on the second floor (Figure 4d) is used after dinner for a few hours in the evening instead of the northern terrace on the first floor. Because the southern terrace faces a public road, the wind flows frequently, making the residents feel comfortable. In addition, during this season (in August), not much solar radiation enters the southern terrace on the second floor, so the temperature does not increase.

The wife uses the first-floor bedroom during the daytime when she feels too hot on the northern terrace on the first floor.

The second-floor bedroom is used for sleeping during the night-time. While the doors are closed, the louver windows remain open for ventilation (Figure 4 b). When the residents are home, they always use the ceiling fan. When they feel hot, they use the air conditioner for 1 or 2 hours and switch it off before sleeping. They feel slightly hot in the second-floor bedroom in the evenings because solar radiation enters the room through the west-side windows, even though bamboo shades are installed on the outside of the windows.

Table 1. Locations in the house where the residents stay and their thermal sensations.



Thermal condition in each space

Figure 5 shows the temperature variability in the dining/kitchen, 1st-floor northern terrace, 1st-floor bedroom, 2nd-floor northern and southern terraces and 2nd-floor bedroom over a period of 2 days.

The outdoor temperature rises to 35°C–36°C during the daytime and drops to 26°C–27°C at night. The temperature in the 1st-floor northern terrace, where the residents mainly stay during the daytime, is 4°C lower than that of the outside. The temperature is lowest at 07:00 in all rooms. Because of the large heat capacity of the floor, the surface temperature of the floor stays at 29°C, which is lower than the air temperature in the morning. Although solar radiation reflects on to the courtyard, it does not enter the 1st-floor northern terrace. Therefore, the actual temperature on the 1st-floor northern terrace also does not rise and remains lower than that of the outside air temperature. Therefore, the low radiation temperature caused by the cool floor and walls makes the residents feel comfortable on the terrace.

Between 09:00 and 16:00, the temperature in the 1st-floor bedroom is the lowest in the house (remaining under 31°C) because of the large heat capacity.

The temperature in the 2nd-floor bedroom increases to 32°C–34°C at 15:00 and remains over 30°C even at 21:00. This is a slightly hot and uncomfortable night-time condition. The temperature increase is due to the solar radiation entering through the windows on the west side.

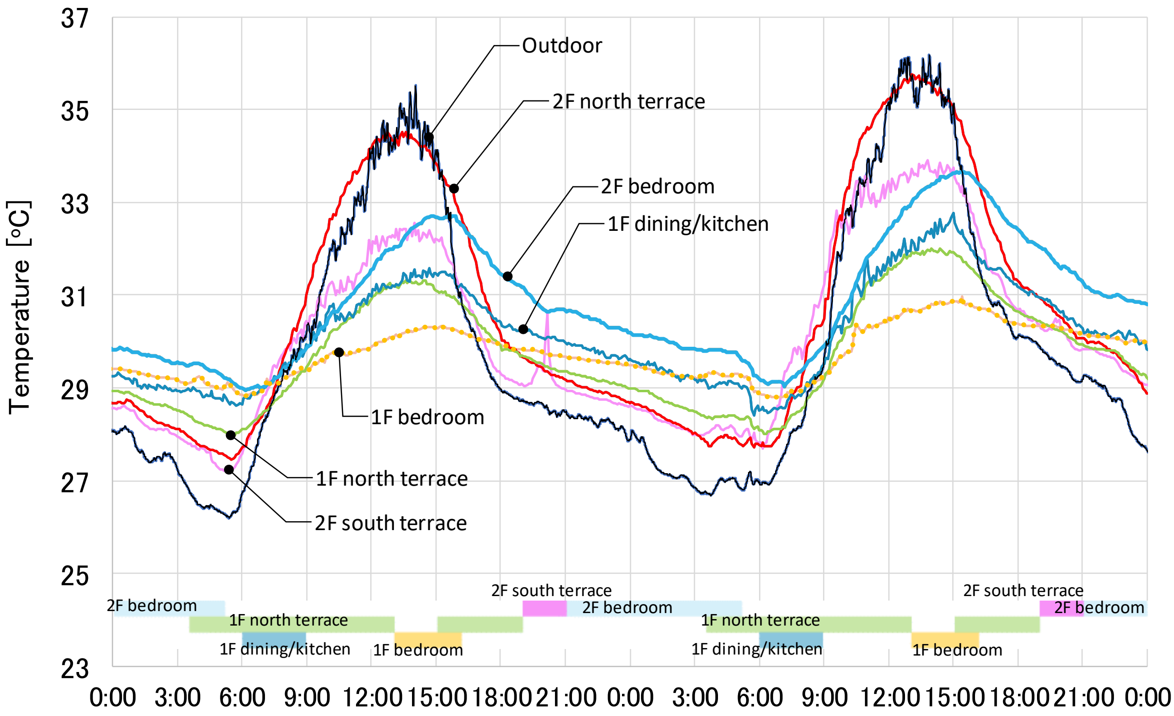


Figure 5. Measured temperature and relative humidity in each room.

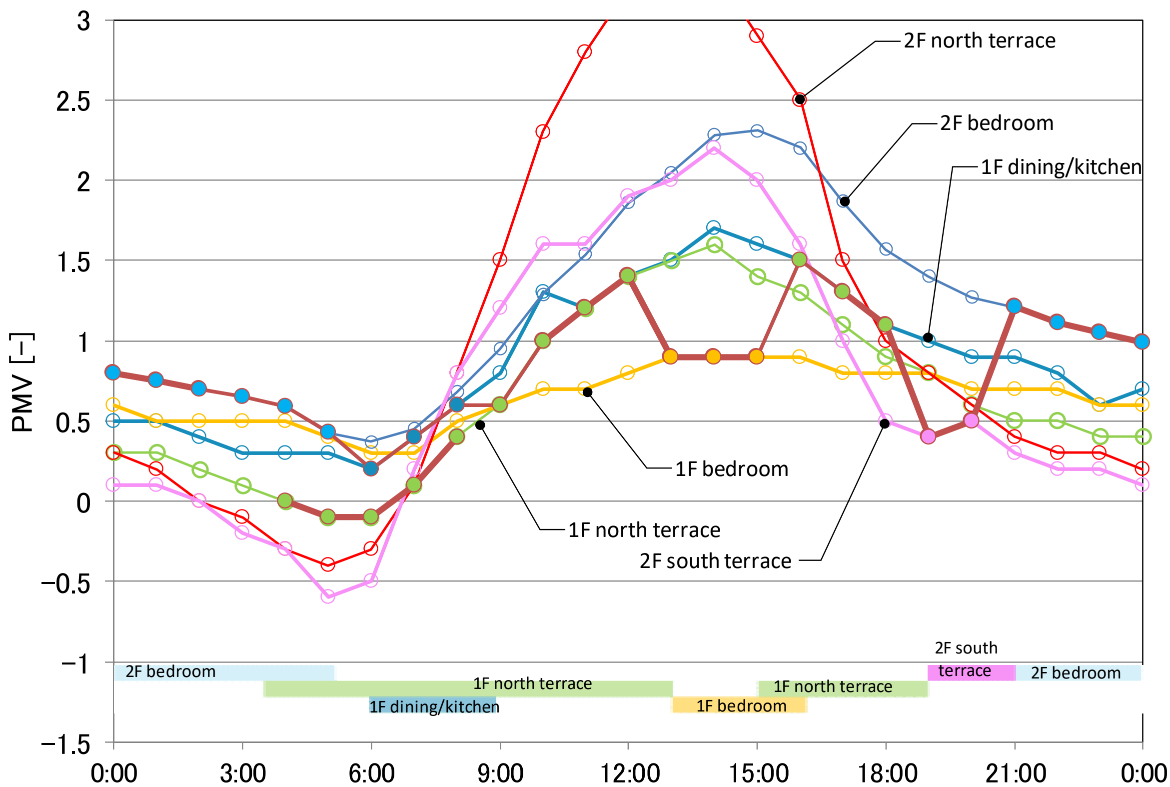


Figure 6. Predictive mean vote (PMV) in each room on August 31.

The temperature on the 2nd-floor southern terrace starts to rise before 06:00 and drops quickly after 15:00. When the residents stay on the terrace, which is mainly in the evenings (21:00), the temperature in this location is 29°C, which is the lowest in the house. Wind flows of around 0.5–3.0 m/s are often present, making the residents comfortable and cool. While the temperature on the 2nd-floor northern terrace decreases during the night, it is still higher or the same as the outdoor temperature in the evening. During this season (between March and October), the sun stays in the north in the daytime. Therefore, the northern terrace reflects direct solar radiation. Between November and February, when the sun stays to the south during the daytime, the condition of the northern terrace becomes better than that of the southern terrace.

The residents choose to stay on the 1st-floor northern terrace in the morning, where the temperature is lowest, and then when they feel hot, they move to the 1st-floor bedroom, where they are able to keep cooler. In the evening before sleeping, they move to the 2nd-floor southern terrace, where the temperature falls quickly and a good flow of wind makes the residents feel comfortable. When they feel hot in the main bedroom, they use the air conditioner for 1 or 2 hours. However, staying in the cooler 2nd-floor southern terrace before sleeping allows for reduction in air-conditioner use.

Thermal comfort of space where residents stay

Figure 6 shows the predictive mean vote (PMV) in the dining/kitchen, 1st-floor northern terrace, 1st-floor bedroom, 2nd-floor northern and southern terraces and 2nd-floor bedroom on August 31, 2016. The PMV is calculated using the measured temperature and relative humidity. The metabolic ratio of the resting condition (1.0met) is assumed as the constant value. The insulation of the clothes, which are T-shirts and short pants, is assumed to be 0.3 clo. The mean radiant temperature (MRT) is assumed to be equal to the room temperature. The normal wind velocity is 0.5m/s because of the natural ventilation flow through the dining/kitchen or the terraces. When no air-flow is present, the residents use either a ceiling fan or a portable fan.

In Figure 6, the PMV in each room is shown in outlined circles, whereas the PMV in the spaces where the residents stay throughout the day are shown as solid colour circles. The values of the PMV in these spaces are in the range between −0.1 and 1.5, which is equivalent to thermal sensations of 'neutral', 'slightly hot' or 'hot'. Even though the condition in the dining/kitchen area is hot, the actual thermal sensation may be lower than that of the estimation, because the average of the measured wind speeds around 14:00 was 1.3 m/s, which is higher than 0.5 m/s used in this estimation. Thus, in the daytime, it can be said that they choose the more comfortable locations from a thermal sensation viewpoint. During the night-time, the PMV in the bedroom on the second floor is almost the same as the condition in the 1st-floor bedroom and slightly higher than that of the other rooms. However, because the residents use the ceiling fan the metabolic ratio is smaller than the estimated value (1.0 met), the actual condition should be better than the estimation.

Assuming the residents stay in the bedroom on the second floor both during the daytime and evening, they should feel hot and will rely on using air conditioners for several hours to avoid being uncomfortable because of high temperature. There is no single space that has an optimal condition throughout the day. However, because there are several locations of different thermal conditions, they can choose the best location each hour. This behaviour can contribute to a reduction in air-conditioner use and, consequently, energy consumption. It is, therefore, highly important to make several spaces with different thermal environments to achieve a sustainable lifestyle.

Conclusion

The behaviour of people in choosing optimal thermal conditions in their house was investigated by conducting interviews with the residents and undertaking field surveys of the thermal environment. It is clear that the residents change location at various hours during the day on the basis of where they think the most comfortable conditions in the house prevail. The locations that the residents choose to be located during different times of the day have comfortable thermal conditions that were better than conditions in other locations.

There is no single space with an optimal condition throughout the day. However, because there are several locations of different thermal conditions, they can choose the best location each hour. This behaviour can contribute to the reduction of air-conditioner use and, consequently, overall energy consumption. It can be concluded that the behaviour to choose optimal spaces and thus reduce air-conditioner use results in a more sustainable lifestyle. It is important to make several spaces in the house with different thermal environments. This behaviour can contribute to energy savings and a better quality of sustainable life.

Note

1. The residents are slightly older. However, the aim of this study was to consider the effect of the people's behaviour in choosing optimal spaces in terms of the thermal environment. The thermal conditions of several spaces in the houses can be compared and evaluated on the basis of their thermal sensations. In terms of future studies, we will survey houses where several generations of the family live.

Acknowledgment

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Opportunities of Ground Duct Ventilation in Greenhouses

Peter van den Engel[1,2], Guiu Riera Sayol[1] and Willem van der Spoel[1]

[1]Delft University of Technology
[2]Deerns Consulting Engineers The Netherlands

Abstract: Greenhouses in The Netherlands contribute significantly to the total energy consumption of the country. One of the leading Dutch philosophies for greenhouses is "the new growing" which reduce energy and improve health, quality and growing of plants: a greenhouse with an adaptive kind of comfort with a free running climate. Heating is necessary to prevent cold stress of plants or condensation. The relative humidity should be just low enough to prevent heat stress of plants or development of fungus. Ground ducts can reduce heating and cooling of air, reverse stratification, improve circulation and dehumidification. These ducts are heated up during the day by the air from the top of the green house, above the screens. In the thermal buffer of the ground solar heat is accumulated and released in the cold early morning. After measurements in a greenhouse with ground ducts, a calculation-model in Matlab is developed and validated. The diurnal temperature-swing in a ground duct is evaluated with the mathematic model of Hollmüller. Via the Matlab-model the energy savings and the effect of the amount and size of ground ducts can be predicted. The system has proved to create better developed tomatoes with almost no diseases anymore.

Keywords: Greenhouse, ground-duct, stratification, screens, circulation

Introduction

In greenhouses, main issues are reduction of heating energy, increasing the CO_2-level to support the growing of plants and reduction of plant diseases. This is the basis of the development of the idea of the "(almost) closed greenhouse concept". Another challenging concept is "the greenhouse as an energy source", an energy producing, high productive greenhouse. Within the scope of the almost closed greenhouse concept an air-soil heat exchanger can improve indoor climate. With a ground duct-system it is possible to store a surplus of energy in the ground during the day, using it on cold moments, often in the early morning. Another goal is the prevention of cold draught via the screens due to better mixing of hot and cold air in the greenhouse. Other research about ground ducts in greenhouses showed that savings of 1 to 5 m^3 of natural gas per m^2 are possible, depending on the mutual distance of the ducts and type of outdoor climate (Raaphorst, 2012). A circulation control-system with ground-ducts can generally maintain a relative humidity below 90 %. Traditionally, dehumidification is realized via operable windows, since the humidity inside the greenhouse is generally higher than outside. This system has disadvantages, such as unnecessary heat- and CO_2-loss and draught. The duct-system that is evaluated here is applied in a greenhouse in 's-Gravenzande in the Netherlands, sized 160 x 90 x 5 m. The heat is extracted from the top of the greenhouse, above transparent screens, and transported to the ground ducts, which end just above the ground (figure 1 and 2).

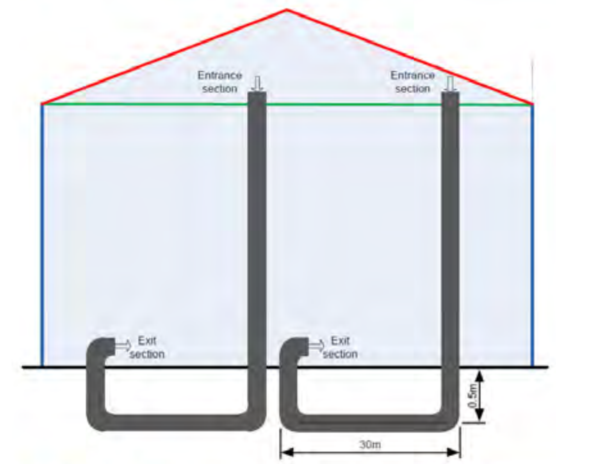

Figure 1: Cross-section of the ventilation principle. The height of the screen is 5 m above the ground.

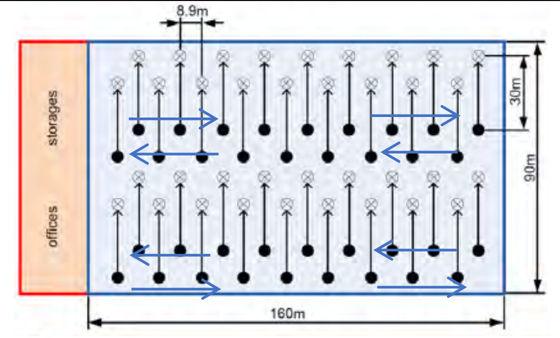

Figure 2: Top view. Black dots: air-intakes. Circles with a cross inside: outlets. Extra fans near the ground improve circulation (horizontal arrows).

The concept is developed by the greenhouse-keeper, Frans van Antwerpen. Each duct is 30 m long, has a diameter of 160 mm and a supply fan. The measured air velocity in the duct is 7.8 m/s. In order to improve the quality of the plants, stagnant air should be prevented and effective air circulation is necessary. As a consequence of the air circulation created by the first prototype of ground ducts, tomatoes until around 10-meters distance of the exhaust were bigger than the rest of tomatoes in the greenhouse. This motivated the idea to install more ground ducts. The current mutual distance of the ducts is circa 9 m. There is still no general consensus yet about how much and what kind of circulation in greenhouses is necessary. The plants near the duct-openings grow better, even with a limited (mechanical) air flow of 565 m^3/h per duct, which is equal to a total ACH of 0.28 for the greenhouse. Small fans just above the ground, perpendicular to the ducts, with a capacity of 100 m^3/h are added and always in use (figure 2). Due to induction the circulation rate is still unknown, but expected to be 1 - 2. Making use of the experience at the Delft University of Technology with greenhouse-simulation (Taal et al, 2013) and ground duct systems (Van der Spoel et al, 2014), it was possible to develop a mathematical and physical model. As background information the philosophy of the “new growing” (Geelen et al, 2015) is relevant as well. The way of using “the new growing” differs per greenhouse-keeper. Plant-growing is very much dependent on the amount of daylight, CO_2-level and the temperature. The more daylight, the higher the metabolism. In order to keep the CO_2-level high, windows should be closed as much as possible. This will increase the temperature. High temperatures in the greenhouse - to a certain maximum - are for many plants not a problem as long as the humidity level remains between the desired boundaries. Via stomata in the leaves CO_2 is absorbed and O_2 is produced via carbon assimilation ($6CO_2 + 6H_2O$ + light = $O_2 + C_6H_{12}O_6$). A high metabolism is only possible with a high percentage of leaf stomata. This makes a plant sensitive for drying out. This can be prevented by a high humidity level. This explains why for many plants a high temperature and a high humidity level are perfect boundary conditions for a sound and fast development. On top of that, plants have a high cooling capacity due to evaporation, as long as there is enough water supply, which can be more than 400 W/m^2 (10 l/m^2 evaporation per day). Due to evaporation the temperature in the greenhouse can remain 4 ^oC below the outside temperature. This explains why it does not become very hot in a rainforest and why in greenhouses with tomato’s non-transparent sunscreens are generally not used, even on very hot days. The cooling effect of an air duct is circa 23 W per m duct and negligible with the cooling effect of plants. Prevention of overheating by operable windows in combination with evaporative cooling is usually enough. Another important requirement of greenhouse-climate is that temperature-swings should be gradually. Here is a striking relation between human adaptive comfort and adaptive comfort for plants. Most greenhouse workers are - to a certain level - also adapted to high temperatures and humidity levels. If necessary, they limit their working hours till 13:00 h on very hot days. The usage of screens (transparent or not) is very much dependent on the type of plants. Pot plants are protected against the sun by screens that reduce solar radiation. For tropical plants that need high internal temperatures and humidity levels often double screens are used. The humidity level remains a critical parameter in all circumstances. The absolute humidity should always be circa 1.9 gram below the maximum, in order prevent heat stress and fungus on plants. Ground ducts are especially effective in autumn when the outside air in the night is cold and humidity level in the greenhouse is high. Increasing the insulation of greenhouses will increase the humidity level, because the condensation on the coldest surfaces will decrease. Consequently, humidity-control, combined with an effective air circulation, becomes more and more important. Other relevant functions of the screens are the reduction of downdraught during cold nights, the improvement of the insulation of the roof of a greenhouse and prevention of lighting hinder to the surroundings (with non-transparent screens). Cold air can flow down via openings between or via the screens depending on their porosity. A ground duct ventilation system reduces this downdraught, by better mixing of cold and warm air.

Methods

The temperature and relative humidity of the discussed greenhouse is measured continuously. In the duct, the velocity and temperature are measured as well. The control-system is installed by Greenspec in addition to the existing climate-control system. To make an evaluation possible data is stored and shared. The greenhouse simulation-model is an extension and adaptation of the recent developed simulation model of de Haagse Hogeschool and the OTB-institute (Taal et al, 2013, Guerra Santin et al, 2015). The OTB-model is validated with the greenhouse program KASPRO from the University of Wageningen. For this research, the model of the OTB-institute is extended with ground duct-ventilation, more detailed control strategies and building physical boundary conditions. Originally, the ducts were modeled with one node and its interaction with the soil was evaluated by Koschens and Lehmann method (Van der Spoel et al, 2005; Koschens et al, 2000). The model from Koschens and Lehmann calculates the output temperatures as a function of the input temperature via resistances in series that simulates the behavior between the air in the ground duct and the soil. For the validation of the model, this method is compared with Hollmüller's method (Holmüller, 2002) which gives exact mathematical results for a harmonic input in the ground duct, where the soil around the duct is considered to be infinite. For longer periods, more than a month, the results of this comparison were pore. Finally, an adaptation of Koschens and Lehmann's method in the Matlab and Simulink-model is used, which gives accurate results for diurnal swings. The model is optimized with the support of W.H. van der Spoel who designed several other ground duct systems (Van der Spoel et al, 2014). The final simulation-model includes the ducts subdivided into 5 different control volumes and the soil refined with 5 thin cylindrical layers around the ducts. The width of the cylindrical layers corresponds to what it is considered to be the thermal affected soil. The rest of the soil is modelled as flat layers along the entire greenhouse area, increasing its width while being deeper in the ground. The model is verified with real data from the greenhouse measured every 61 seconds. The measured outgoing temperature is compared with the calculated one. The optimal size of and velocity in the ducts was evaluated earlier by Mike Olsthoorn of the Haagse Hogeschool (2014) and Paepe et al (2003). The optimal length of the ducts proved to be circa 30 m with a diameter of 160 mm and the air velocity could be reduced to 2 m/s, instead of 7.8 m/s. Even at a velocity of 2 m/s there is still a high exchange efficiency due to turbulence near the wall of the duct. The total pressure difference over a duct-system can be reduced to circa 10 % of the current 275 Pa at 7.8 m/s.

Theory

The simulation is based on a linear matrix system with 50 nodes representing temperatures that have to be calculated every 1200 seconds over 8760 hours (one year). By simulating and determining all these temperatures from array T condensation, relative humidity and energy consumption is calculated, presented as: $A \cdot T = B \cdot Q$. An energy balance for each node is calculated using the relations showed in figure 3 and 4. Each term of the equations is classified either on the left side with a to be calculated temperature or on the right side with known data. The temperatures in each node can be calculated with iteration: $T = A^{-1}BQ$. In order to merge the greenhouse with the ground duct-system, the temperatures have to be calculated at the same time, known as implicit system. Loops have to be avoided and the equations are integrated in the Matrix system. This also reduces avoidable inaccuracies, caused by explicit systems. The model from Koschens and Lehmann uses a combination of 4 different resistances (figure 5). Nevertheless, only R_x has been used and the rest of the resistances has been changed by a refined system of nodes that simulate the change of temperature along the ducts and its air (figure 6). These nodes represent cylindrical soil layers around the duct. Koschens and Lehmann's method provides a resistance calculation that connects the outer temperature of the duct and the core temperature of the soil, found between two ducts, in the same plane. The duct has been divided in 5 sections, with a length of 6 meters each. By this distribution fast changes in temperature can be simulated. Following the movement of the air inside the duct, advection simulates this air flow. Each air node takes as an input the air from the previous air node and its air temperature is taken as an output. Using the geometrical characteristics of the system and the air properties, the convection between the air and the duct surface is calculated. From the duct node to the top of the layers, conduction thermally relates one node with its upper and lower adjacent nodes. The most important assumption is the non-interaction between duct and soil nodes that are at the same level. Therefore, the air interacts with the five duct nodes and from this time on, the mathematical equations only relate vertical positioned nodes (figure 4). This assumption has been evaluated with a mathematical test. The resistance R_x represents the resistance encountered by the heat to flow between the outer surface of the "equivalent duct" and the core temperature of the ground layer in the middle point between ducts. This core temperature is the same as the center of the star-shaped resistance representation, core temperature of soil layer 6, represented in figure 5. Due to its meaning, it depends on the geometrical characteristics of the duct and the thermal conductivity of the soil. After verifying the air-soil heat exchanger

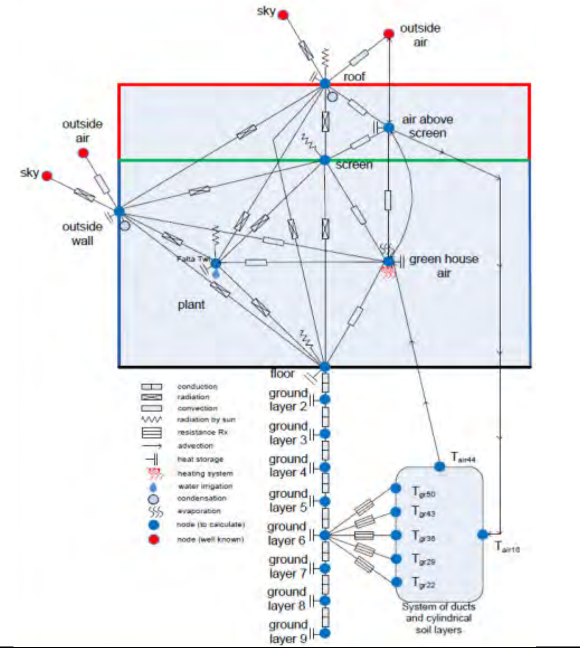

Figure 3: The relation between nodes. The air-soil heat exchanger is shown only by its interaction with the rest of the system.

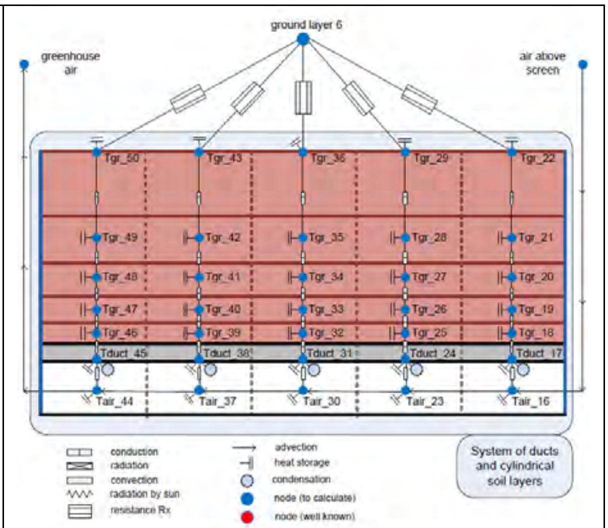

Figure 4: The relation between all the nodes related to the system of air-soil ground ducts.

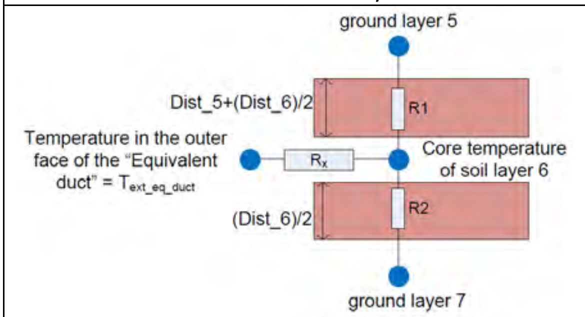

Figure 5: Diagram of Koschens and Lehmann method applied to the greenhouse simulation.

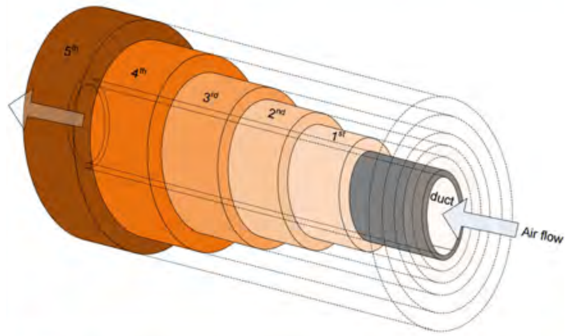

Figure 6: Ground duct mesh where the duct is covered by 5 cylindrical soil layers. It can be seen in color grey the hollowed duct and then the 5 cylindrical soil layers, all with the same soil properties. The size of the cylinder is 0.42 m.

with the mathematical model of Hollmüller, it is compared with real data of a greenhouse equipped with sensors. The ground duct system has been tested with a measured input temperature.

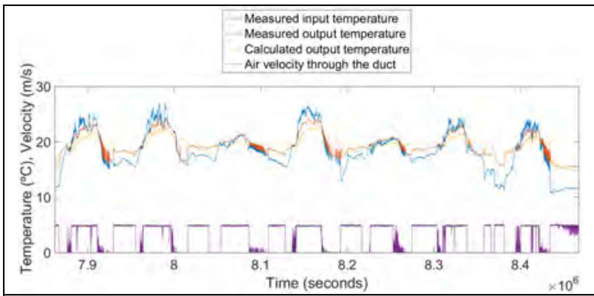

Figure 7: Plot of all the variables in the test during the 13th measured week out of 26.

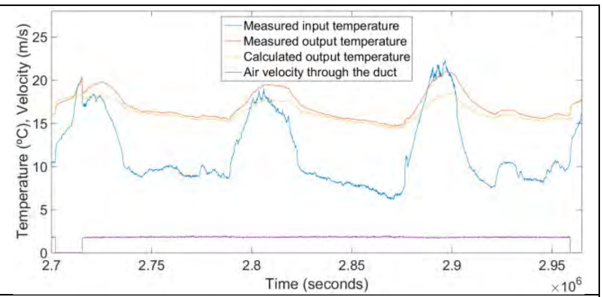

Figure 8: Detail of one of the longest periods where ground ducts are functioning. It corresponds to the period from the 31st until the 34th day.

The calculated output is compared with the measured temperature in the exhaust of the ground duct. Stored-temperature data for 183 days in a row is used which was measured every 61 seconds. Furthermore, the air velocity inside the duct is measured, giving also information about when the system is in use (figure 7 and 8). The model gives some inaccuracies for high inlet temperatures but they can be explained with two different parameters. Firstly, the inaccuracies are greater when the ground ducts are not working. This is not a problem because the calculated different is caused by the temperature of the greenhouse air and not due to the errors caused by the air-soil heat exchanger. Secondly, the greater differences are observed in the peaks of the input, which can be assigned to the heat caused by condensation inside the greenhouse, which is not yet calculated in the test. The effect of condensation can be better seen in figure 8. Finally, the results are also compared with previous research (Olsthoorn, 2014), a single zone model of the ground-duct. The differences of the measured and calculated outlet temperatures are reduced from circa 2,0 to 0,5 ^{o}C.

Results

After validation of the simulation, the greenhouse system was simulated. First, the greenhouse consumption without ground-ducts is taken as a reference. Later, 36 ground ducts are added, being continuously in use as long as the greenhouse has plants. The reference situation leads to a consumption of 840 MJ/m^2. A continuous flow of 7.8 m/s leads to a higher consumption of 842 MJ/m^2, 2 % higher than the reference, so it is obvious that the system should not use the ducts continuously. The program calculates different outputs for every time step. The optimization function chooses the output with the least consumption. In case of both having the same consumption, the lowest temperature which is still above the optimal minimum is chosen so that the excess of energy can be stored in the ground. Optimization 1 is the system-control of the real greenhouse, where ground ducts can either work at a certain velocity (7.8 m/s) or their fans are stopped. In Optimization 2 there is velocity-control of the air through the ducts, leading to a varying convection-coefficient between the air and the duct, with different ratios of exchange of energy. The following velocities are simulated: 0.5, 1, 2, 4 and 8 m/s. Because high air velocities lead to high energy consumption (pressure drop), 8 m/s has been kept as the maximum velocity. The third optimization combines speed-controlled fans with the ground covering, called Optimization 3 (table 1). When plants are cut there is still much energy stored in the ground, either through the ground ducts, transmission or solar radiation that penetrated to deep layers. The temperatures in the end of the year at the start of the new grow-season are higher with ground covering. Results are presented in table 2.

Table 1

Summation of the optimization methods used for the calculations with its characteristics.

Optimization	Velocities [m/s]	Measure
1	0; 7.8;	-
2	0; 0.5; 1; 2; 4; 8;	-
3	0; 0.5; 1; 2; 4; 8;	Ground covering

Table 2

Energy consumption along a year for the three different optimization methods and 36 ground ducts.

Simulation	Consumption [MJ/m^2]	Savings
No ground ducts	829.6	-
Optimization 1	828.4	0.15%
Optimization 2	827.0	0.31%
Optimization 3	822.8	0.82%

Note: Percentages are relative to the greenhouse without ducts.

Limited savings are obtained with 36 ground ducts, which are 8.9 meters apart from each other. Optimization 2 compared with 1 doubles the savings. With ground covering savings are 2.6 times higher than with Optimization 2. However, covered ground is (almost) the current situation. In the final simulations the amount of ground ducts and the optimization method are varied. Table 3 and figure 9 present the results for all the simulations. Van der Spoel (2014) and Raaphorst (2012) already showed that increasing the amount of ducts has economic benefits. The optimum amount of ducts depend on more parameters, like the practical usage of space and daylight. A distance of circa 2 m seems to be the optimum for this greenhouse with energy savings around 0.4 m^3 gas per m^2. In theory 1,131 ducts are possible, with some overlap of the cylinders of figure 6.

Table 3

Energy consumption during a year for the three different optimization methods.

Amount of ducts	Distance between ducts [m]	Optimizing method	Consumption of natural gas [MJ/m^2]	Consumption of natural gas [m^3 gas/m^2]	Savings of gas [m^3 gas/m^2]
0	-	-	829.6	23.6	-
36	8.9	1	828.4	23.5	0.03
		2	827.0	23.5	0.07
		3	822.8	23.4	0.19
100	3.2	1	827.0	23.5	0.07
		2	823.9	23.4	0.16
		3	819.6	23.3	0.29
320	1.0	1	821.2	23.3	0.24
		2	815.9	23.2	0.39
		3	811.4	23.1	0.52
640	0.5	1	812.3	23.1	0.49
		2	806.5	22.9	0.66
		3	801.8	22.8	0.79
1131 (max)	0.42	1	801.1	22.8	0.81
		2	794.7	22.6	0.99
		3	789.9	22.4	1.13

Note: In order to convert the consumption measured in MJ into m^3 of gas, 35.2 MJ/m^3 gas has been assumed.

Ground ducts are used differently in the seasons. Its overall usage is 21% of the time. In spring ground ducts are mostly used in the night and early morning. In summer most usage is during the hottest hours of the day by cooling the greenhouse. In an autumn ground ducts are mostly used from the early morning to the mid-afternoon. In the coldest week of the year ground ducts are mostly used in the afternoon.

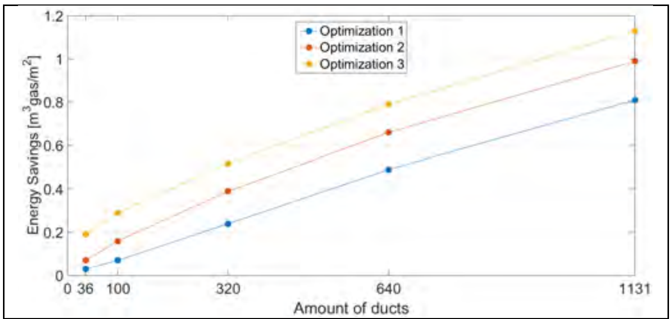

Figure 9: Energy savings that can be found for different amount of ground ducts using *Optimization 3*.

Discussion and conclusion

The Matlab-model makes a conservative estimation of the energy savings by ground-duct ventilation in greenhouses. The amount of savings is rather small (circa 0.2 – 1.2 m^3 gas per m^2), but more than enough (2.880 – 17.280 m^3 gas) to compensate for the electricity energy for the duct-fans, which is estimated as 4.000 kWh for the current situation without fan-optimization. The energy savings by condensation in the ducts and less heat-losses by the active heating system is not yet taken into account. A single fan, supported by the fan-characteristic, can also supply 4 ducts with almost the same effectiveness. Due to this effect, with around 160 ducts, the electricity consumption will hardly rise. The most positive effect is less-stratification and downdraught, effective air circulation, fewer usage of windows and better dehumidification leading to a better health and growing of plants. This was the main reason to install the current system. In addition to better insulation of roof and walls, usage of the earth remains an interesting option of the future to improve climate in greenhouses and can make additional ductwork and fans above the ground almost superfluous. Other optional improvements are active heating, cooling and dehumidification via the ducts and connection of the duct-system to outside. The condensation-calculation in the model still needs improvement. These optimizations will be studied in the next future.

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Renewed Trombe wall passively reduces energy consumption

Yvonne Wattez[1], Tudor Cosmatu[1], Martin Tenpierik[1], Michela Turrin[1], Florian Heinzelmann[2]

[1] TU Delft, Delft, The Netherlands [2] SHAU Architecture and Urbanism, Bandung, Indonesia

Abstract: In order to reduce the energy demand of households, a new type of Trombe wall is being designed during a 'research through design project' called 'Double Face 2.0'. A Trombe wall is a passive system that reduces the energy demand of a building. In winter, it captures the heat from the sun during the day and releases this heat into the building at night. In summer, it captures the heat from internal sources during the day and releases that heat at night towards outdoors. First simulations showed that our prototype of a lightweight, translucent, adjustable Trombe wall reduces the energy demand for heating of a typical Dutch household by 25-30%. Instead of stone-like materials, the new type of Trombe wall will consist of translucent materials: phase change material (pcm) and insulating aerogel. The insulation gives the opportunity to direct the thermal mass of the pcm. In this way, the system is adjustable for cooling and heating purposes. A selection of the design concepts is described in this paper, explaining the design choices and method of validation. Depending on the level of detail, different simulation software has been used. This paper describes the comparison and the experiences of using it.

Keywords: Trombe wall, passive, heating, cooling, pcm

Introduction

Although there has been a lot of progress towards energy efficiency of households since 2000 (Gerdes, 2015), we still need to strongly reduce the energy demand of buildings in order to reach the European 20-20-20 targets (European Union, 2017). In the Netherlands, the majority of the energy consumed in households is used for heating. Nevertheless, the share of energy demand for cooling to prevent overheating increases.

During the two 'research through design' projects 'Double Face 1.0 and 2.0', a new type of Trombe wall is being designed in order to reduce the energy demand for both heating in winter and cooling in summer. A traditional Trombe wall is a passive system consisting of a massive stone-like wall placed behind a glazed façade. In between the glass and the wall a thin layer of air exists (Saadatian et al, 2012). Furthermore, it is common practice to install controllable vents at the top and bottom of the wall enabling air exchange between the inhabited space behind the wall and the thin layer of air whenever required. In winter, the Trombe wall captures the heat from the sun during the day and releases this heat slowly into the building in the evening and at night. Whereas the traditional Trombe wall was designed to be only used in winter, with adjustments it could also be used in summer. In summer, it then captures the heat from internal sources during the day and releases that heat at night towards outdoors by a combination of ventilation cooling and nocturnal radiation towards a clear sky. A new development in modern variations of the

Trombe wall is the inclusion of phase change materials in order to decrease the weight of the wall (Saadatian et al, 2012; Castellon et al, 2009; Fiorito, 2012; Kienzl, 1995; Manz et al, 1997; Weinläder et al, 2005). All of these Trombe walls, however, are fixed in place and can hardly be adjusted to the dynamics of the environmental conditions.

The Trombe wall presented in this paper consists of translucent materials: phase change material (pcm) and insulating aerogel. The insulating layer gives the opportunity to direct the thermal mass of the pcm towards either the room or the window. Furthermore, the system’s configuration can be adjusted so that it can be used for both cooling and heating purposes. This novel Trombe wall can be used in existing and new buildings.

This paper presents two of the design concepts, explaining the design choices and the methods of validation. Depending on the level of detail, different simulation software has been used.

Double Face 1.0

During the project ‘Double Face 1.0’, a first adjustable, translucent Trombe wall has been developed (Figure 1). Instead of concrete, the elements are filled with 4 cm pcm type RT25E2. This pcm has a transition temperature for melting and freezing around 25^{o}C and a latent heat storage capacity of 180 kJ/kg (Rubitherm, 2015). According to a numerical study by Bourdeau, a 15 cm concrete wall can be replaced by a 3.5 cm wall of phase change material and perform similarly (Bourdeau, 1980). By using pcm, a more lightweight system was developed with a thermal storage capacity similar to a traditional Trombe wall. Apart from the pcm, the Double Face Trombe wall consists of 1 cm of translucent Lumira aerogel insulation with a thermal conductivity of 0.018 W/(m·K) (Cabot, 2017). Both the pcm and aerogel are encased in transparent containers with a shape as can be seen from figure 1 (right). All together these modules form a 3D undulated Cairo pentagonal tiling pattern.

Figure 1. Artist impression and photo of the first adjustable translucent Trombe wall prototype.

Besides the use of new materials, the adjustability of the system plays an important role. If the pcm is facing the window during a winter day, it stores the energy of the sun. After rotation at night, the pcm faces the inhabited room in order to release the heat into the room. In summer, the cycle reverses: during the night, the pcm faces the window and releases the heat by night ventilation and nocturnal radiation towards the sky. During the day, the pcm faces the inhabited room and stores heat from internal sources. If the room temperature rises above 22°C, the pcm slowly starts melting. The higher the room temperature, the quicker the melting process, with an optimum at 25°C. During this process the temperature of the pcm stays stable; it only rises again after the pcm has fully molten.

To prevent the Trombe wall from taking away the view to outside, openings were realized in the design. Simulations in Design Builder v3.4 showed that the best trade-off between unobstructed views and heat storage capacity would lead to a ratio of approximatively 10% of openings in the system's overall surface. When increasing the percentage of openings, the heat transfer via convection between the cavity and the room increases which reduces the advantageous time lag of the Trombe wall.

One of the strengths of this new Trombe wall system is the ability to rotate the elements in order to orient the pcm either towards the room or to the window. Because Design Builder is not able to move or rotate elements during a simulation, a Matlab/Simulink model was set-up to simulate a 2D flat Trombe wall that rotates twice per day. The model is a full energy performance model for a small room with a window facing South including solar gains, internal gains, ventilation and infiltration losses, transmission losses through the façades, heat storage in walls, sun-blinds, temperature set-points, schedules, etc. The ceiling and floor were assumed to be adiabatic surfaces. Relevant settings are presented in Table 1.

Table 1. Settings used for the simulations in Matlab/Simulink.

calculated time (one winter)	1 Oct. - 30 Apr.	% of holes in Trombe wall element	10%
orientation Trombe wall	South	thickness of PCM	varies
size of room w*d*h	3.6*5.4*2.7 [m3]	thickness of insulation layer of Trombe wall	0.01 m
window to wall ratio South	80%	PCM: specific heat	2000 J/(kg·K)
window to wall ratio North	40%	PCM: density	1450 kg/m3
U-value of glass	1.65 W/m2·K (double glazing)	PCM: thermal conductivity	0.6 W/(m·K)
Rc-value of opaque walls	3.0 m2·K/W	PCM: latent heat of fusion	1.8·105 J/kg
solar heat gain coefficient - no sunblind	0.6	Insulation material: specific heat	1440 J/(kg·K
occupancy	18.00-8.00 h / 7 days a week	Insulation material: density	75 kg/m3
Internal heat gains	1.8 W/m2 according to NEN 7120 for dwellings	Insulation material: thermal conductivity	0.012 W/(m·K)
Ventilation rate of the room	1.2 when occupied	weather data	Dutch NEN5060 B2 reference weather data
PCM in solid phase	< 23 Celsius	set-point temperature of heating system	20oC
PCM in liquid phase	> 26 Celsius		

The results of the simulations are shown in Figure 2. It gives an overview of the amount of energy needed to heat the room. During one winter period, the energy use of this room without a Trombe wall would be 4.78 GJ. If a Trombe wall of 4 cm concrete is added, the heating demand is reduced to 3.71 GJ. When the concrete is replaced by an insulated and adjustable Trombe wall (rotates 180^o twice per day) of 4 cm pcm and 1 cm aerogel, the required energy drops to 3.18 GJ; a reduction of 33%. The optimal thickness, though, lies at 1-2 cm of pcm with a decrease of 30-32%. With these insights, new design concepts are being developed during the Double Face 2.0 project.

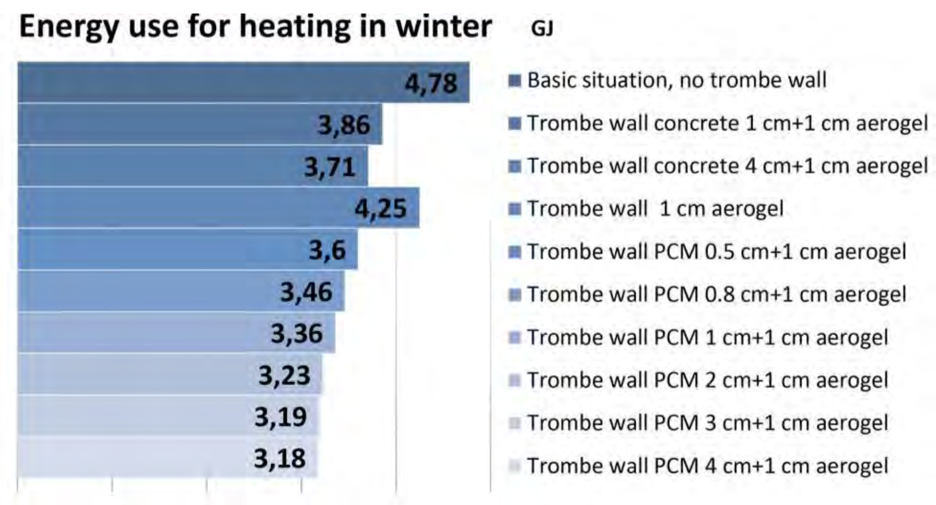


Figure 2. Results regarding the energy use.

Double face 2.0: a selection of developed designs

With the goal of a lightweight, adjustable, translucent Trombe wall, eleven different design concepts have been developed during the 2.0 project so far. Two of these concepts are explained in this paper: the 'Trombe panel' and the 'Jacobs ladder'.

Trombe panel

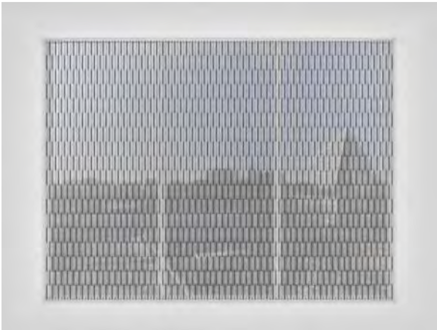
This design integrates thermal, structural and optical properties in one aesthetically designed panel. The panel stands behind a window and needs to be vertically rotated by hand or by an electro-motor, in the morning and afternoon. The design is based on a brain coral pattern which is filled with pcm with a melting temperature of around 25^{o}C. Due to this pattern some parts are filled with pcm and some parts remain open for view. The thickness of the pcm in the panels varies to optimize the translucency for daylight at certain positions. The total volume stays the same as for a flat panel with a thickness of 2 cm pcm.

The yearly energy savings resulting from the use of this Trombe wall are similar to the ones calculated with the Matlab/Simulink script in a previous section (Figure 2).

Figure 3. Design impression of Trombe panel concept

Jacob's ladder

The design concept 'Jacob's ladder' is based on a movement principle. The elements of the Trombe wall need to flip sides twice per day to orient the pcm in the required direction. The movement in this design comes from a toy (figure 5). If the ladder is held at one end, blocks appear to cascade down the strings. This effect is a visual illusion which is the result of one block after another flipping over. An arrangement of interlaced ribbons allows each block to act as if hinged to the next one at either of its two ends. An impression of the design is shown in figure 4 where the black, vertical lines show the strings of the ladder.



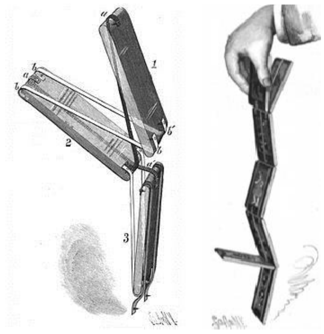


Figure 4 (left). Design impression of Jacobs ladder concept.
Figure 5 (right). Principe of Jacob's ladder movement (Scientific American, 1889).

Double face 2.0: selection of simulation results

Jacob's ladder

More detailed simulations are used to compare different design variations of the 'Jacobs ladder concept'. Therefore, a 2D simulation model in the program COMSOL v.5.2 was made. This program allows to simulate 2D and 3D models over longer time periods; import geometries; simulate with moving elements; simulate with real weather data; and use the same model for more detailed CFD-simulations (Computational Fluid Dynamics).

A simplified version of the Jacob's ladder design is shown in Figure 6, with 2 cm of pcm and 1 cm of aerogel, the properties of which are shown in Table 1. The floor, ceiling and walls are made of concrete and contain an adiabatic boundary along the outside. Heat transfer only takes place through the South façade with the Trombe wall via conduction and radiation from the sun. The opaque walls of this façade have a U-value of 0.34 W/(m^2·K); the double glass has a U-value of 1.65 W/(m^2·K). Moreover, no heating system is active, no sun-shades are used and no people are present inside the room. The panels rotate around their centre at fixed times: at 8:00h and 18:00h. The weather data used is shown in Table 1.

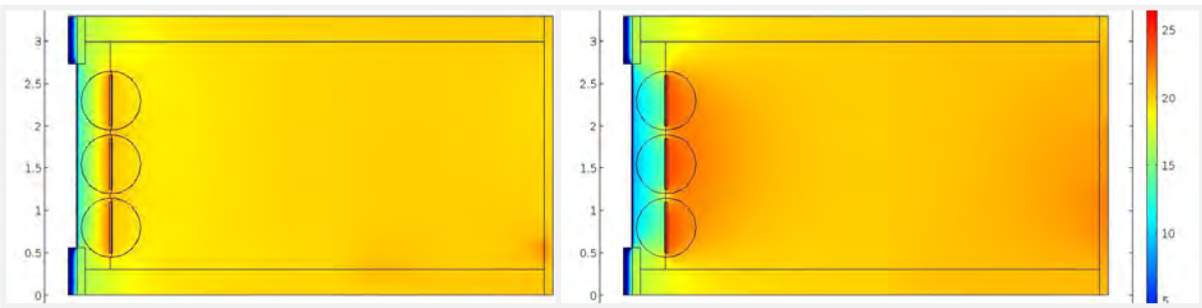


Figure 6. Simulation result of Jacob's ladder design concept; vertical cross-section of a room.
Left: January 9, 12.00h - pcm faces window. Right: January 10, 00.00h; pcm faces room

Figure 6 (left) shows the temperatures on day 9.5 (January 9, 12.00h) so the pcm faces the window and the aerogel faces the room whereas figure 6 (right) shows the temperatures on day 10.0 (January 10, 00.00h) when the position of the pcm and aerogel are reversed. Solar radiation clearly heats up the cavity during the day, visualized by the red colours on the left side of the panels. Some sunlight passes through the openings in between the panels, indicated by the orange dots in the bottom right corner. In the evening, the pcm, which now faces the room, clearly radiates heat into the room. The circles in the model are necessary to simulate a rotating mesh and are not part of the design.

The effect of the use of different materials

In order to understand the effect of material types and thicknesses in the Jacob's ladder concept, different configurations of this basic model were simulated in Comsol (Table 2). Figures 7 and 8 show the simulation results for Jan. 1 till Jan. 21, giving the average room temperature per configuration and the average temperature of the thermal mass component (pcm or concrete). The effect of the solar radiation is clearly visible in both graphs. The pcm heats up quickly in the configurations with 2 cm pcm. The release of the heat takes a long time. A thicker layer of pcm (7 cm) gives a more stable room temperature and a lower temperature of the pcm itself, see the purple line in Figures 7 and 8.

The positive effect of rotating the pcm panels on room temperature is visible in the results of day 0-10 where the red line, the rotating Jacob's ladder, shows a higher and more stable room temperature than both the configurations without a Trombe wall and with non-rotating panels. The rotating pcm Trombe wall is able to maintain a comfortable room temperature in winter for many days after a day of moderate sunshine (2.8 kWh/m^2 of global normal radiation on day 2) without the need for an additional heating system.

The advantage of pcm above concrete is also visible in the graphs. Where the concrete Trombe wall extracts heat from the room during day 10-20, the pcm stabilizes the room temperature and uses the radiation of the sun to heat. If the pcm temperature is always within the transition range on freezing and melting (shown by 'PCM_trans' in Fig. 8), the room temperature is stable. This is for instance the case for a Trombe wall of 2 cm of pcm facing the room and 1 cm of aerogel facing the window (1P_ins_room). The pcm is barely heated up by the direct sunlight because of the insulating layer, so its temperature stays within the transition range. Nevertheless, this configuration does not use the incoming solar radiation for heating the room optimally; for that the pcm needs to face the window.

Table 2. Different configurations simulated in COMSOL.

name	*description*	*material 1*	*material 2*	*rotate*
No_Trombe	no trombe			
Concrete_30	classical 30 cm	concrete 30 cm		no
Concrete_15	classical 15cm	concrete 15 cm		no
1P_7cm	pcm 7cm	pcm 7 cm		no
1P_2cm	pcm 2 cm	pcm 2 cm		no
1P_ins_window	pcm to window, 2 cm, insulated	pcm 2 cm	aerogel 1 cm	no
1P_ins_room	pcm to room, 2 cm, insulated	pcm 2 cm	aerogel 1 cm	no
3P_rotate	3panels pcm rotate	pcm 2 cm	aerogel 1 cm	yes
3P_room	3panels no rotate pcm to room	pcm 2 cm	aerogel 1 cm	no
3P_window	3panels no rotate pcm to window	pcm 2 cm	aerogel 1 cm	no

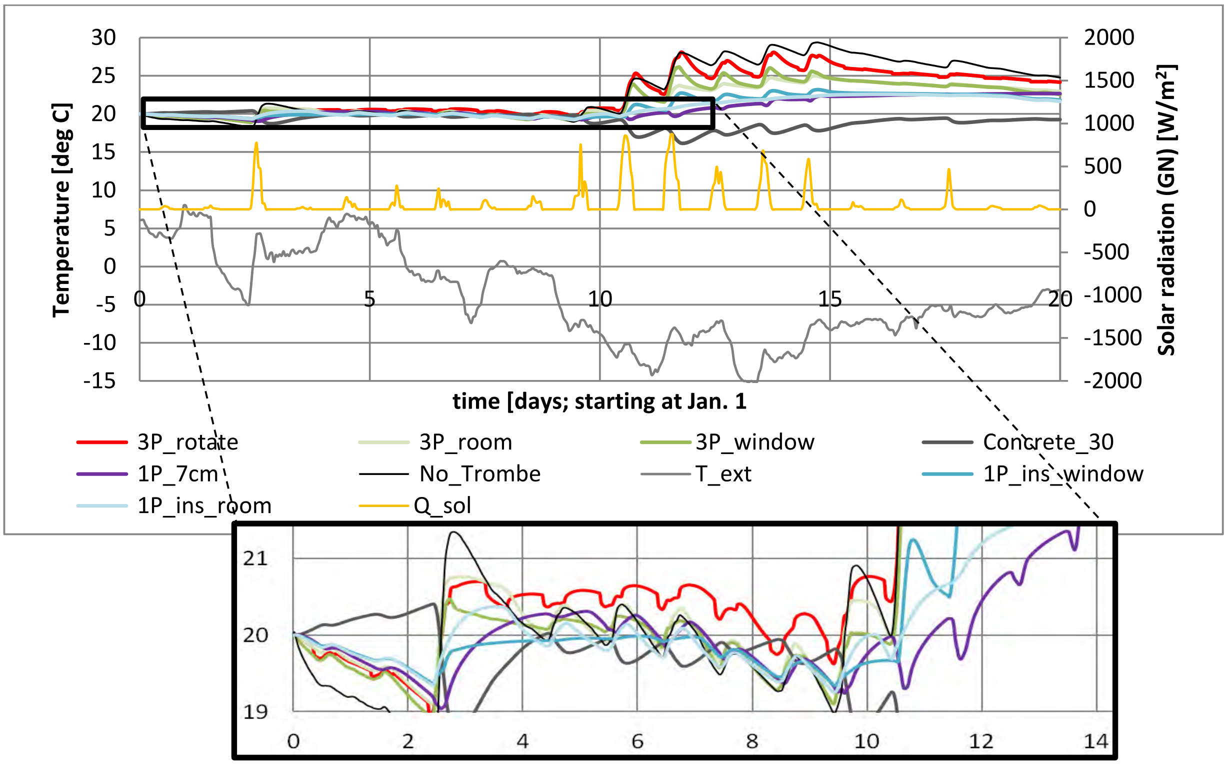


Figure 7. Room temperature due to Jacob's ladder concept from Jan. 1 - 21; no heating / room unoccupied.

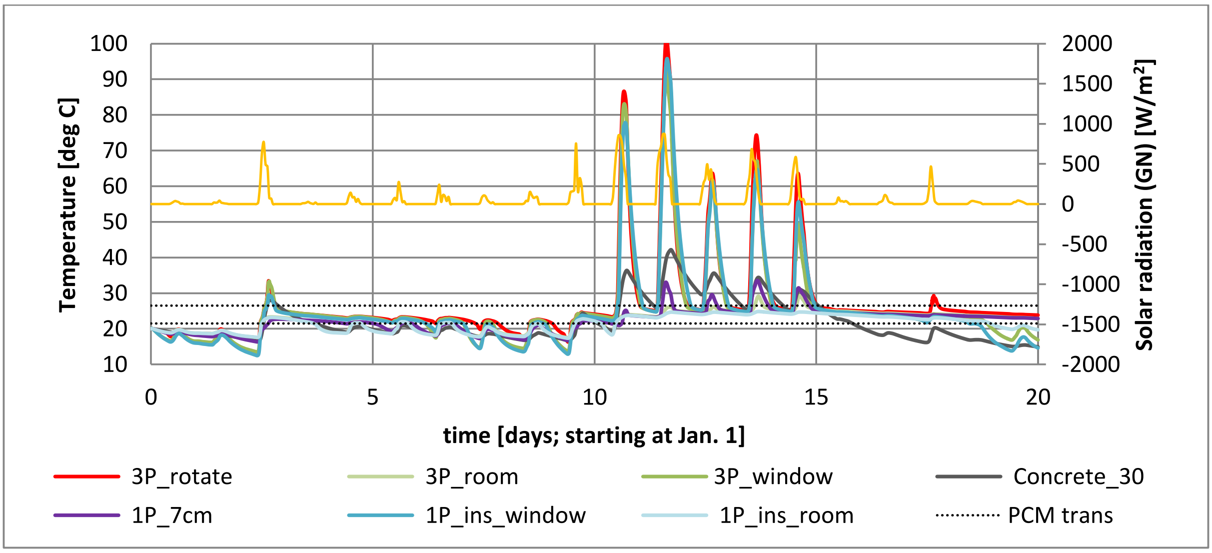


Figure 8. Pcm temperature due to Jacob's ladder concept: average temperature of thermal mass component.

Conclusions

This paper describes a novel, adjustable, lightweight, translucent Trombe wall containing pcm and an insulation layer of translucent aerogel. One of the strengths of this wall is its adjustability allowing the pcm to face either the window or the inhabited room. As a result, the system can both be used in winter in heating mode and in summer in cooling mode.

Several design concepts have been developed, two of which were described in this paper. Simulations with a model developed in Matlab/Simulink, that includes the adjustability of the system, have shown that a layer of 2 cm pcm together with an insulation layer of 1 cm aerogel can reduce the heating demand of a room in the climate of the Netherlands by around 30%. More advanced simulations with a 2D model in Comsol have shown that in case of a well-insulated room, this 2 cm of pcm heats up very fast due to the solar radiation. To prevent it from overheating and to optimize the heating capabilities, the design should be equipped with a thicker layer of pcm in winter. However, since the release of the heat takes longer than the absorption of it, the extra pcm might be unwanted during summer where the transition works in reverse.

The simulation results showed the advantages of the rotation of the elements during a sunny winter day. However, on a cloudy winter day, the pcm slightly cools the room. During the next phase of the project, smart rotation algorithms will be investigated in order to optimize the thermal effect of the system. As such, innovative Trombe walls may be an important means of passively reducing the energy demand of buildings.

Acknowledgement

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The climate-responsive design strategies of ancient timber-frame halls in northern China: a field study

Hong Xu[1], Qiong Huang[1], Anxiao Zhang[1], Qi Zhang[1]

[1] School of Architecture, Tianjin University, Tianjin 300072, PR China

Abstract: The risks of global warming and the depletion of fossil fuels call for a re-examination of traditional buildings. Although vernacular dwellings have received considerable attention, few studies investigate other building types. In this paper, the thermal environments of ancient timber-frame halls in northern China were investigated based on field measurements to obtain more evidence of traditional ecological ideology and related strategies. Six typical halls with different orientations, openings, and ceilings but similar spatial scales and materials were selected; their air temperature, relative humidity, air speed, surface temperature, and globe temperature on typical summer and winter days were measured. The results show that the indoor environments are comfortable in summer but too cold in winter. Further analysis shows that the key strategy for comfort in summer is to have high heat capacity to provide shelter from hot air and solar gains; natural ventilation is considered to be merely an auxiliary approach. Climate-responsive design strategies for winter consist of a south-facing orientation with a maximum window-to-wall ratio and significant thermal insulation to utilize solar gains and to provide shelter from cold air.

Keywords: ancient timber-frame hall, cold region, climate responsive design, thermal comfort, field measurement

Introduction

The risks of global warming and the depletion of fossil fuels call for a re-examination of traditional buildings. However, because almost all the traditional buildings involved in the above studies are vernacular dwellings, little attention has been paid to other building types, such as traditional buildings for the purposes of administration, sacrifice, religion, and education. Since vernacular dwellings have more similar functions and design principles with contemporary residential buildings than public buildings, their climate-responsive design strategies have been applied mostly to contemporary residential buildings accordingly.

In China, the electricity consumption per unit area of a large public building is 10 to 20 times that of a residential building due to the energy-intensive solutions. Therefore, it is necessary to revisit public buildings that were designed and constructed in ancient times.

Ancient timber-frame halls are one of the main public building types in ancient China. The primary difference between the halls and vernacular dwellings is size. In addition, they differ in their exterior forms, interior decorations, materials and details according to their official status and function. These differences could lead to differences in their climate-responsive strategies, which could be more applicable to contemporary public buildings.

This study aims to (1) investigate the indoor environments of ancient timber-frame halls and (2) discover the climate-responsive strategies used in them. In this study, the thermal environments of six ancient halls in northern China were measured in summer and winter. Based on the measurement results, the thermal comfort of each building was evaluated using the adaptive model proposed by GB/T 50785-2012, the Chinese standard for evaluating indoor thermal environments. Then, the results were analysed comparatively, and some building design elements were found to have important influences on the indoor thermal environment. Finally, conclusions were drawn to outline the climate-responsive design strategies.

Ancient timber-frame halls in northern China

General data on the geography and climate of northern China

China can be divided into four geographical regions in terms of location, natural conditions and cultural background: the northern region, the southern region, the northwest region and the Qinghai Tibet region (Figure 1a).

Figure 1. Geographic location and climatic data, a. four geographical regions of China, b. five climate zones in China and c. distribution of ancient halls in the climate zones in northern China.

Figure 1b shows the five climatic zones in China: the Severe Cold Zone, the Cold Zone, the Hot Summer and Cold Winter Zone, the Hot Summer and Warm Winter Zone, and the Mild Zone. Most of the ancient timber-frame halls in northern China are located in the Cold Zone (Figure 1c). The Cold Zone typically experiences cold, dry winters and hot, humid summers. In January, the mean minimum temperature varies between -10.4 and -4.0°C, and the mean maximum temperature ranges from 0.7 to 4.2°C. In July, the mean minimum temperature falls within the range of 18.8~23.4°C, and the mean maximum temperature falls within the range of 29.5~31.1°C.

Description of the ancient timber-frame halls

Throughout history, the Chinese have always employed an indigenous system of construction. An ancient timber hall consisted of a platform, a structure with a timber post-and-lintel skeleton and a curved roof (Figure 2). The raised platform served as the base of the structure, and the structure supported the curved roof with overhanging eaves. This construction permits complete freedom for walling and fenestration and, by simply adjusting the proportion between the walls and openings, renders a building practical and comfortable in many climatic conditions while also meeting the other occupant needs.

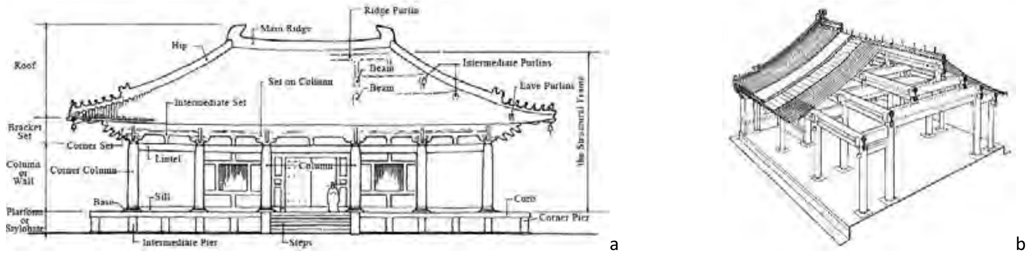

Figure 2. Structural system of an ancient timber-frame hall, a. principal parts and b. isometric view.

Outline of the field measurements

Building descriptions

The six timber-frame halls selected for this study were Xiang Hall of the Imperial Ancestral Temple (Building TM), Guanyin Pavilion of the Dule Temple (Building DLS), Long'en Hall of the Putuo Yu Ding Dongling (Building CX), Long'en Hall of the Puxiang Yu Ding Dongling (Building CA), Daxiongbao Hall of the Huayan Temple (Building HYS) and Daxiongbao Hall of the Shanhua Temple (Building SHS) (Figure 3). These halls were all built in different dynasties and were regarded as typical representatives of ancient halls in their own time. They shared similar external environments but differed in orientation, openings and ceilings, which were assumed to affect the indoor thermal comfort.

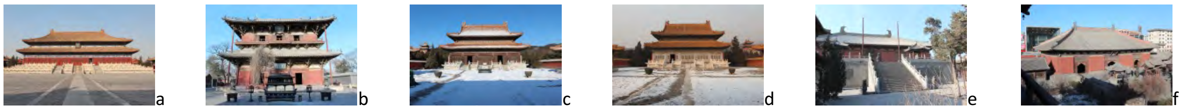

Figure 3. Studied buildings, a. Building TM, b. Building DLS, c. Building CX, d. Building CA, e. Building HYS and f. Building SHS.

To protect these cultural relics, all modern renovations are prohibited, and none of the halls have been fitted with HVAC, lighting, or other systems except Building TM, which has heating and lighting due to certain historical reasons. The use of electric equipment has also been prohibited. This means that their indoor thermal environments are mostly influenced by climatic conditions, building elements and occupants.

Measurement items

The factors that were measured were air temperature, RH, air speed, surface temperature and globe temperature. The measurement points were distributed according to the sizes, layouts and elevations of the studied halls. All of the parameters except the ground surface temperature were measured at a height of 1.7 m to represent individuals in a standing position as recommended by ISO 7726.

Measurement period

Every measurement was conducted on a day that was clear or cloudy with a temperature within the typical range of summer or winter. Because these timber-frame halls are tourist attractions, some regulation authorities restricted the duration of measurement to 24 hours. In addition, these six halls are located in four cities, and only Building CX and CA are located adjacent to each other, so measuring all of them simultaneously is unavailable. To ensure that the halls would be measured under similar weather conditions, the time intervals between the measurements were compressed as much as possible.

Measurement results and thermal comfort evaluation

Measurement results

In summer, the indoor air temperatures of all six buildings fluctuated from 22.52 to 29.46°C, which is a smaller range that falls within the range of the outdoor temperatures, i.e., from 20.31 to 34.88°C. Furthermore, the halls' thermal environments were uniform with very small standard deviations, i.e., from 0.12 to 1.01°C.

The variation tendency of the indoor RH is consistent with that of the outdoor RH, but in most cases, it fluctuates over a smaller range. The temperature and the RH have an inverse relationship in every building. For example, in summer, the outdoor RH of Building

CA varied from 45.8% to 59.0%, and the corresponding indoor RH varied from 56.9% to 65.7%. In winter, when the outdoor RH varied from 41.5% to 47.3%, the corresponding indoor RH varied from 38.8% to 47.9%.

The positions of doors and windows are known to affect the indoor air environment, as shown by the fact that the air speed of all of the buildings except Building DLS is too low to be perceived. Building DLS was measured with its doors open, including the six that face south and the six that face north; therefore, its indoor air speed ranged from 0.01 to 0.31 m/s when the outdoor air speed ranged from 0.13 to 1.70 m/s in summer, and its indoor air speed ranged from 0.03 to 0.45 m/s when the outdoor air speed ranged from 0.16 to 0.73 m/s in winter. Regarding the other buildings, their doors and windows face a single orientation, resulting in stagnant indoor air despite an occasional breeze near the open doors.

The exterior surface temperatures of the walls and doors vary significantly with orientation and fluctuate dramatically when they are affected by sol-air temperatures. However, the interior surface temperatures are relatively stable and consistent. In addition, the variation tendencies of the ground surface temperatures are consistent with those of the wall surface temperatures.

There are small differences between the globe temperatures and the corresponding air temperatures, which implies that there is weak thermal radiation from the interior surfaces.

Thermal comfort evaluation

The thermal performances of the ancient halls were evaluated using GB/T 50785-2012, which is the Chinese standard for evaluating indoor thermal environments. The range of comfortable temperatures (t_{op}) in northern China can be estimated from the running mean of the outdoor temperature (t_{rm}) in °C using the equations shown in Table 1. Category I is for thermal environments that satisfy more than 90% of their users, and Category II is for environments that satisfy 75–90% of their users.

Table 1. Calculation method for the comfort temperature.

Category	Evaluating indicator	Restricted range
I	$t_{op\ I,b} \le t_{op} \le t_{op\ I,a}$ $t_{op\ I,a} = 0.77t_{rm}+12.04$, $t_{op\ I,b} = 0.87\ t_{rm}+2.76$	18 °C $\le t_{op} \le$ 28 °C
II	$t_{op\ II,b} \le t_{op} \le t_{op\ II,a}$ $t_{op\ II,a} = 0.73t_{rm}+15.28$, $t_{op\ II,b} = 0.91t_{rm}-0.48$	18 °C $\le t_{op\ II,a} \le$ 30 °C, 16 °C $\le t_{op\ II,b} \le$ 28 °C, 16 °C $\le t_{op} \le$ 30 °C
III	$t_{op} < t_{op\ II,b}$ or $t_{op\ II,a} < t_{op}$	18 °C $\le t_{op\ II,a} \le$ 30 °C, 16 °C $\le t_{op\ II,b} \le$ 28 °C

The results of the calculations show that, in summer, the indoor environments of Buildings TM, DLS and CX fall within the Category II comfortable range, and those of Buildings CA, HYS and SHS fall within the Category I comfortable range. In winter, the indoor environments of all of the buildings except Building TM fall below the comfortable range.

Analysis of climate-responsive design strategies

Climate-responsive design strategies in summer

According to the thermal comfort evaluation, the indoor environments of all ancient timber-frame halls meet the basic requirements for thermal comfort in summer, which indicates that their climate-responsive design strategies are mostly effective for relieving heat.

The indoor air temperatures, RHs, and interior surface temperatures of all six buildings fluctuate over much smaller ranges than the corresponding outdoor parameters, which indicates that the building envelopes of ancient halls have high heat capacities. In addition, thermal interactions between the outdoor and indoor environments can be identified using the calculated correlation coefficient. In summer, the mean correlation coefficient of the six buildings is 0.81 (Figure 4a), which suggests that these buildings interact with their environment and that their building envelopes function as permeable boundaries.

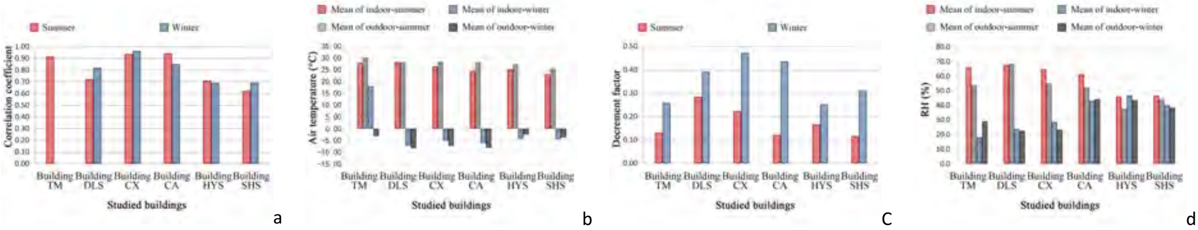

Figure 4. Further analysis of the measurement results, a. the correlation coefficients of the studied buildings, b. the mean air temperatures of the studied buildings, c. the decrement factors of the studied buildings, and d. the mean RHs of the studied buildings.

However, these buildings have some differences in thermal performance that can be detected through the comparative analysis of the measurement results. First, it is clear from Figure 8b that the mean indoor temperature of Building DLS is close to the mean outdoor temperature, while the mean indoor temperatures of the other buildings fall below the mean outdoor temperature. The primary difference between Building DLS and the other buildings is the position of the openings. In summer, the outdoor temperature is higher than the indoor temperature during the day. Therefore, indoor-outdoor air exchange could increase unnecessary heat gain through ventilation and worsen the indoor thermal environment.

Second, no time lag between the outdoor and indoor temperatures is observed in Building CX and CA; however, the other buildings exhibit time lags ranging from 1 to 3 h. Numerical and laboratory studies have reported that the insulation thickness has a very profound effect on the time lag. As the thickness of the wall increases, the time lag increases; when the wall thickness increases beyond a certain limit, the time lag becomes 24 h, and it seems as though there is no time lag. From these results, it can be concluded that Buildings CX and CA have longer time lags than the others, which could mainly be due to the actual opening ratios of the doors and the windows. As more doors and windows are opened, more thermal exchange occurs between the indoor and outdoor environments, which reduce the insulation performance of the building envelope.

Third, the decrement factors of the six buildings are shown in Figure 4c. Building DLS has the largest decrement factor, followed by Building CX and then Building HYS; the decrement factors of the other buildings are small and close together. Regarding Building DLS, it is obvious that cross-ventilation has an important influence on the decrement factor. The difference between Building CX and the other buildings is the ceiling. Since Building CX and CA are located next to each other and have the same building elements except the ceiling, they were measured simultaneously and their difference in measurement results could indicate the ceiling's influence on indoor thermal environment directly. Compared with Building CX, the air temperature of Building CA is lower and has relatively small fluctuations in summer (Figure 5), which could be attributed to the improved thermal insulation supplied by the ceiling. Building HYS faces east, while the other buildings face south. Obviously, the overhanging eaves of these ancient halls do not keep solar radiation out on summer mornings, reducing the insulation performance of the building envelope and increasing the decrement factor.

Fourth, the mean indoor and outdoor RHs are compared in Figure 4d. Because the indoor temperature is lower than the outdoor temperature during the day, the indoor RH is higher than the outdoor RH. This phenomenon occurs in most of the studied buildings, but Building DLS is an exception. The indoor RH of Building DLS is close to the outdoor RH, which is related to its efficient ventilation. Although the lack of ventilation in the summer can reduce unnecessary heat gain and maintain a good thermal environment, it also results in a high RH, which might threaten structural safety and the users' health.

Finally, there are also differences between the studied buildings in terms of the relationships between the surface temperatures of the inside walls and the floors. In Buildings DLS and HYS, the inside walls have lower surface temperatures than the floors (Figure 6), and in the other buildings, the inside walls have higher surface temperatures than the floors. In summer, the surface temperatures of the outside walls are dramatically affected by the sol-air temperature, and those of the inside walls are affected by the heat conducted through the building envelope. The floor surface temperatures may increase if sunlight and hot air enter the buildings. In Buildings TM, CX, CA and SHS, the surface temperature of the inside walls is higher than that of the floor. This indicates that the sol-air temperature has a stronger influence on the walls than on the floor, meaning that the envelopes of these buildings effectively mitigate solar radiation and increases in the indoor air temperature. The opposite pattern occurs in Buildings DLS and HYS, which could be related to the ventilation of Building DLS and the orientation of Building HYS.

Based on above analysis, except for the building material, the orientation, ceiling, opening direction and actual opening ratio influence the indoor thermal environment in summer. Although these studied buildings have differences in thermal performance, their indoor environments almost satisfy comfort requirements. It can be concluded that the high heat capacity of the building envelope is the key strategy in summer and can reduce the adverse effects caused by other unsuitable factors. Moreover, ventilation is generally considered the main reason that ancient Chinese buildings remain cool in summer, but this has been proven incorrect by this study. Stack ventilation is only an auxiliary approach.

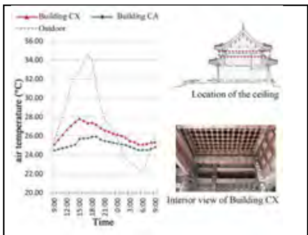	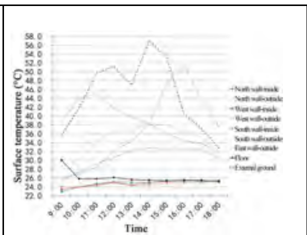	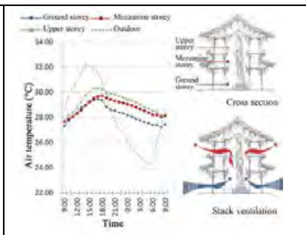	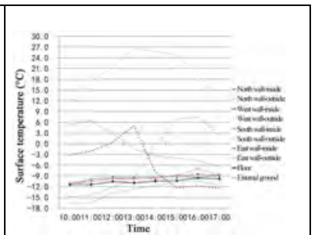
Figure 5. A comparison of the measurement results of Buildings CX and CA.	Figure 6. Time variation of the surface temperature of Building HYS during a typical summer day.	Figure 7. Stack ventilation in Building DLS	Figure 8. Time variation of the surface temperature of Building HYS during a typical winter day

Climate-responsive design strategies in winter

Thermal comfort evaluation indicates that the indoor environments of all of the ancient halls except Building TM fall below the comfort standard in winter. This means that ancient halls have difficulties maintaining a comfortable temperature without artificial equipment, which could be attributed to the cold winter in northern China.

Although the indoor air temperatures cannot meet the comfort demands, their fluctuation ranges are significantly smaller than those of the outdoor temperature. This could reflect the significant heat insulation of the building envelopes. In addition, in winter, the mean correlation coefficient of all buildings except Building TM is 0.80 (Figure 4a). The halls without HVAC systems are able to influence the climate effects when they interact with their environment. Furthermore, because of differences in some building design elements, these buildings have different thermal performances.

First, there are differences in the relationship between the mean indoor and outdoor temperatures. As shown in Figure 4b, the indoor temperatures of Buildings CX and CA are always higher than the outdoor temperatures; the mean indoor temperatures of Buildings DLS and SHS are close to the mean outdoor temperatures; and the mean indoor temperature of Building HYS is lower than the mean outdoor temperature. This demonstrates that orientation and the window-to-wall ratio play important roles in solar gain. In terms of orientation, Building HYS faces east, and the other buildings face south. Regarding the window-to-wall ratio, Buildings CX and CA have the largest values, and the other buildings have the smallest values. Obviously, an east-facing building receives much less solar gain than a south-facing building. Therefore, Building HYS has the worst indoor environment. In the buildings that face south, larger openings significantly increase the solar transmission and improve the indoor thermal environment. This explains why the indoor environments of Buildings CX and CA are better than those of Buildings DLS and SHS.

Second, time lags of 1 h show in Buildings DLS and HYS, and no time lags are observed for the other buildings. In winter, Building DLS has unnecessary ventilation that removes heat from the solar radiation. Building HYS receives very little solar radiation due to its orientation. Therefore, their indoor environments are mainly affected by the outdoor temperature rather than by direct sunlight, and their time lags are caused by the heat storage of their envelopes. Buildings CX, CA and SHS face south, and the positions of their openings restrict heat convection. Consequently, solar radiation has important effects on their indoor environments. In winter, solar radiation reaches its maximum at noon, and the peak air temperature occurs in the afternoon, which could lead to the lack of a time lag.

Third, as shown in Figure 4c, Building HYS has the smallest decrement factor of all of the buildings, which might serve as additional proof that the building envelope's thermal performance is satisfactory. However, it cannot be concluded that Building HYS has the best thermal performance. This view is contrary to the analysis of the other measurement results. Due to this building's south-facing orientation, the indoor temperature, especially the maximum temperature, of all of the buildings except Building HYS increases in response to solar radiation, which expands the temperature fluctuation range and increases the decrement factor. In Building HYS, the lack of solar gain decreases the fluctuation of the indoor environment.

Finally, there is a difference in the relationship between the interior surface temperature of the walls and that of the floor. In Buildings DLS and HYS, the interior surface temperature of the walls is higher than that of the floor (Figure 8). In contrast, the wall surface temperatures in the other buildings are lower than the floor surface temperatures. This can also be attributed to the position of the openings and the orientation of the buildings. Compared to Buildings DLS and HYS, Buildings CX, CA and SHS receive more solar radiation due to their excellent thermal insulation, increasing the floor surface temperature.

In general, the building material, orientation, opening direction and window-to-wall ratio of ancient halls all influence the indoor environment, and these building elements are equally important for maintaining a comfortable temperature.

Conclusions

The thermal environments of six ancient timber-frame halls in northern China were investigated to identify their climate-responsive design strategies in this paper. The measurement results show that the indoor air temperatures of all six halls fluctuated between 22.52 and 29.46°C in summer and between -8.91 and -2.64°C in winter, meaning that the indoor environments were comfortable in summer but too cold in winter according to GB/T 50785-2012. For ancient halls in northern China, their high heat capacity provides shelter from hot air and solar radiation in summer, which is the key to indoor thermal comfort, and stack ventilation is only an auxiliary approach. In winter, the method for creating a comfortable environment is a south-facing orientation with a maximum window-to-wall ratio and significant thermal insulation to not only utilize solar radiation but also provide shelter from cold air.

Climate-responsive design strategies used in ancient halls, such as a suitable orientation, a high heat capacity, plenty of insulation, a rational layout of openings, and reasonable window-to-wall ratio, are still usable in the design of contemporary public buildings. Compared with ancient halls, contemporary public buildings have much higher internal gains, which means that ventilation is critical for the indoor environments of contemporary public buildings. Contemporary public buildings always have a large depth, making cross–ventilation ineffective. Drawing on lessons from ancient halls shows that taking advantage of elevated space, such as an atrium, organizing the openings, and using mechanical ventilation assistance are effective and sustainable ways of ensuring thermal comfort.

Acknowledgements

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Low-income residential design in Guangzhou, China: Regaining the use of transitional spaces

Jiaji Yang[1], Paula Cadima[2]

[1] AA SED Sustainable Environmental Design, Architectural Association School of Architecture, London, UK. yangjiaji77@hotmail.com.
[2] AA SED Sustainable Environmental Design, Architectural Association School of Architecture, London, UK.

Abstract: Since the high rise gated community appeared in China, the sense of neighbourhood seems to have disappeared from the modern city. Moreover, in the hot and humid climatic region of China, the presence of air-conditioning units, typically hanging from the outer walls of dwellings, has made living conditions on balconies and outdoor communal spaces unbearable due to the heat released. In the quest for an alternative to recover these lost facets, a design research explored a courtyard community as a means of providing spatial cohesion and a better neighbourhood. Fieldwork undertaken to assess how the AC contributes to outdoor overheating revealed the importance of free-running. Analytic work was carried out to simulate the impact of various design solutions aiming at improving environmental performance of a base case. The results show that, in addition to a careful design and ventilation, transitional space with shading device, free-running could be achieved. A design application shows the proposed model to provide better thermal comfort indoors as well as quality of social life for residents than local typical residential buildings. This paper discusses the main findings of this study and the design process which led to the proposed design scheme.

Keywords: courtyard, passive cooling, solar control, adaptive architecture, low-income housing.

Introduction

Courtyard communal living involves a group of people living together and sharing one courtyard, which is a traditional living style in China (Figure 1). These courtyards are like a small community. The central courtyard strings each household together and serves as a place for communication and leisure. This charming, cohesive and vibrant public space creates social contacts and an enjoyable living atmosphere. However, as the high-density community develops, the sense of a neighbourhood seems to disappear (Figure 2).

Research Objectives

This paper presents the design process leading to a design proposal for a new residential development for low-income people in Guangzhou. The design development focused on a courtyard community as a means of providing spatial cohesion and a better neighbourhood (Yang, 2016). A key objective was to create a good quality of social life for residents. Another important objective was to provide low-cost accommodations that can achieve thermal comfort conditions throughout the year and eliminating the need for active cooling.

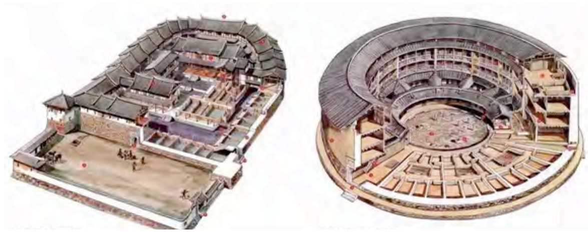

Figure 1. Different typology of courtyard communal living in China (source: Li, 2009)

Figure 2. High-rise development in China (source: gz.58.com)

Climate of Guangzhou

Guangzhou (Canton) is located in South China just south of the Tropic of Cancer, Figure 3. It has a hot summer and a warm winter. The annual average temperature is 23.0 °C with the coldest monthly average temperature of 14.3°C in January and a maximum monthly average temperature of 29.5°C in July. The annual relative humidity (RH) is 68%, with the lowest monthly average RH of 57% in December and highest monthly average RH of 76% in June (Figure 4).

Figure 3. Location of Guangzhou

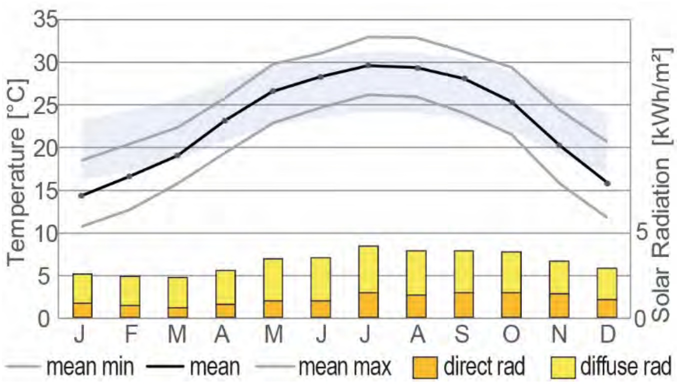

Figure 4. Guangzhou climate (source: Meteonorm 7.0)

Since the weather is cloudy most of the time, the amount of diffuse solar radiation is high, far more than direct solar radiation. Except during October, November and December, the amount of diffuse solar radiation is more than twice the amount of direct solar radiation. Therefore, in addition to controlling direct solar radiation, shading aimed at reducing the diffuse solar gain independently of orientation is also an important design feature.

Field Studies in Tulou Commune

Figure 5. Tulou Commune (source: www.urbanus.com.cn)

The Tulou commune is a courtyard community that aims to be affordable to accommodate low-income migrants in Guangzhou and Foshan (Figure 5). Field studies were undertaken inside this building over a period of four days in August 2016 in order to investigate how a courtyard community performs in an urban environment.

The monitored spaces included one bedroom (without air conditioning), the balcony of a unit located on the third floor and the courtyard (Figure 6). Hourly weather data was obtained from *Weather Wunderground* (2016). Results are shown in Figure 7.

The temperature increase on the balcony is explained by the existence of a split air conditioner outdoor machine, which was used during occupancy hours. This led the balcony to become an intolerable hot and humid place during this period of time. The courtyard temperature follows the trends of outdoor temperature but with a time lag of 1.5-2 hours. During the day the air temperature in the courtyard is lower because the space is shaded by the surrounding buildings. At night, however, the concrete surface and air conditioner units emit heat to the courtyard, increasing the air temperature 2-5K above the outdoor air temperature. Indoors, the air temperature is kept steady at 31-33^{o}C throughout each day. This is possibly due to the combine effect of the thermal mass of the building, the buffering effect of the balcony and courtyard, and the lack of ventilation.

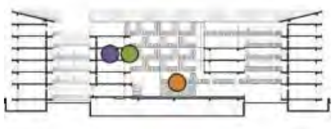

Figure 6. Data logger location

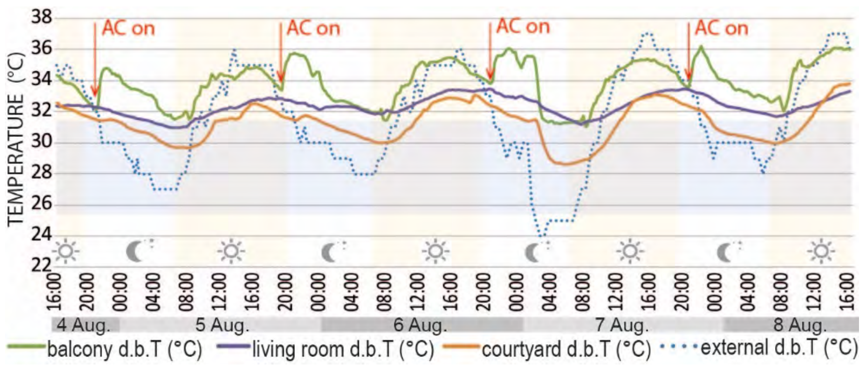

Figure 7. Data logger result

The fieldwork revealed that the discomfort of indoor spaces instigates occupants to install air conditioning units, which releases heat, leading the thermal conditions on balconies and courtyard to become unbearable. Therefore, indoor comfort is the indispensable factor for achieving comfort in an outdoor communal space. Moreover, increasing the air flow inside the courtyard should help removing excessive heat.

Analytic Studies to Improve Environmental Performance

Analytic work was carried out to assess the impact of various design solutions aiming at improving environmental performance of a base case. Parameters studied included solar control and courtyard form.

Solar control

In order to decrease the indoor temperature and achieve a free running apartment, various shading solutions suitable to control both direct and diffuse radiation have been tested with the use of *Ecotect* and *EDSL TAS*. The base case model was defined with a typical living room/kitchen and a 1.2m deep open balcony, Figure 8. Four scenarios, described below, were tested:

Case 1: base case + vertical horizontal shading element
Case 2: base case + horizontal shading element
Case 3: base case + movable vertical panels with horizontal shading element
Case 4: base case + movable horizontal panels with horizontal shading element

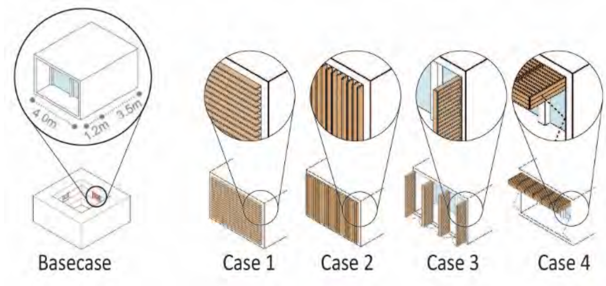

Figure 8. Five cases set up

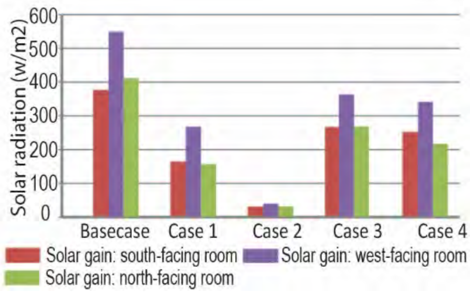

Figure 9. Amount of solar gains (source: Ecotect)

Figure 9 shows the solar gains inside the room for the South, North and West orientations. The scenario described as Case 1 helps blocking about half of the sunlight, while the solution shown in Case 2, the room only captures 30-39 W/m² solar radiation. The study indicates that all the shading panels should feature horizontal shading elements and that the shades should be kept closed during daytime. The solutions shown in Cases 3 and 4 are scenarios for when the occupants need daylighting indoors or to open the shades for more ventilation. The amount of solar gains for both the movable vertical panels (Case 3) and the movable horizontal panels (Case 4) is similar.

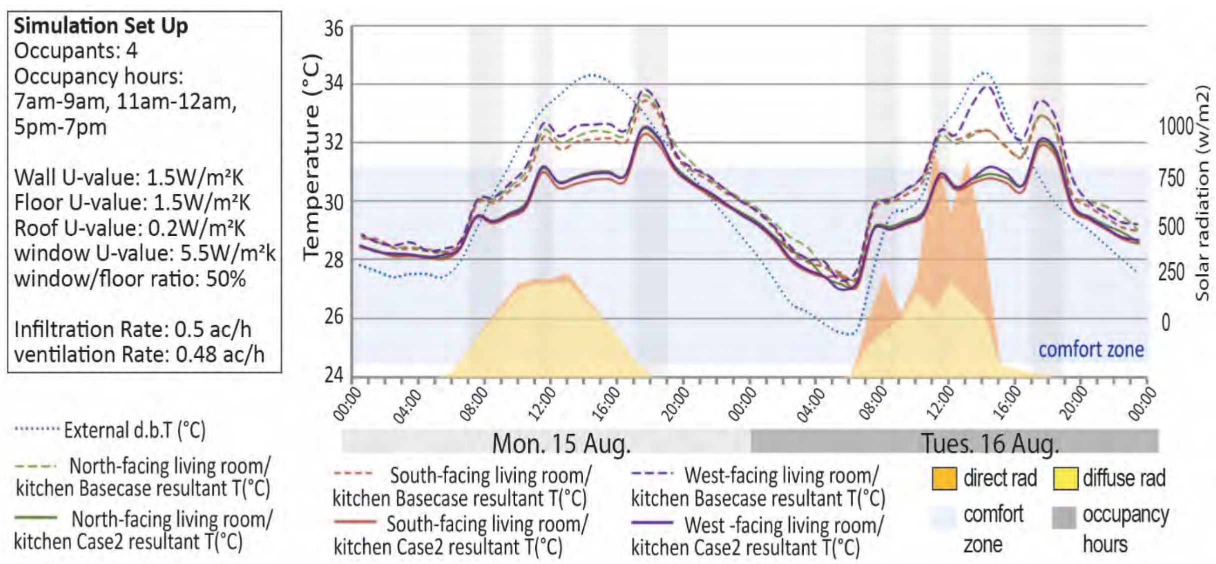

Figure 10. TAS simulation result in summer (source: EDSL TAS)

Figure 10 indicates the resultant temperature inside the room on typical summer days under Case 2. On a cloudy day (the first day), the shade helps reducing the temperature by 1.5K-2K during the daytime, while on a sunny day (the second day) it decreases it 2K on the South and North facing rooms and about 3K on the West-facing room. Except during cooking hours (17:00-19:00 pm), the resultant temperature is consistently in the comfort zone. This shows that the indoor temperatures can be kept within the comfort range if the room is protected by a 1.2m deep balcony overhang and shading panels with horizontal shading elements.

Courtyard Form

As discussed earlier, the courtyard should have openings facing the prevailing wind to let air flow into the courtyard. However, in an urban environment, due to various constraints (e.g. obstruction, regulation), the opening cannot always face the prevailing wind. Therefore, the degree of deviation was analysed, with the help of *WinAir for Ecotect* software, with two kinds of openings, Figures 10 and 11.

Figure 10 shows the effect of different angles between the opening and the wind direction. The air velocity at the central point of the courtyard reaches its highest value when the opening is facing the prevailing wind. The air velocity at the central point of the opening reaches its highest point when the angle is 90^{o}. Figure 11 shows the results when the opening is in the middle. The air velocity at the two points exceeds or is equal than 0.5 m/s only when the orientation angle is less than 45^{o} or equal to 180^{o}. Therefore, in order to enhance air flow penetration inside the courtyard, the angle between the opening and the wind direction should be less than 90^{o}. If the courtyard has the opening in the middle, then the angle between the opening and the wind direction should be less than 45^{o} or equal to 180^{o}.

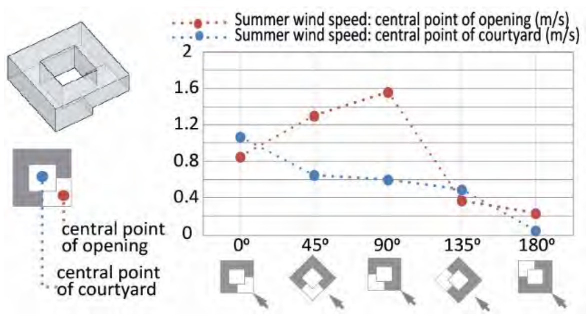

Figure 10. Wind velocity of courtyard centre and opening (opening at corner) (source: WinAir)

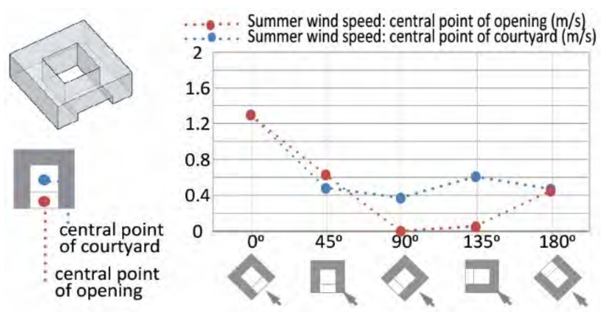

Figure 11. Wind velocity of courtyard centre and opening (opening in the middle) (source: WinAir)

Design Application


Figure 12. The proposed new building scheme

The proposed new buildings were designed for a low-income community located in the city centre of Guangzhou (Figure 12). In China, young Chinese couples tend to live close to their parents to look after one another. Therefore, the unit typology consists of two zones, the lower floor is for elderly couples (grandparents), and the upper floors comprise a duplex for young couples (parents and children). The unit layout is illustrated in Figure 13.

The balconies were designed to protect the space from the strong solar radiation from all orientations. Additional adjustable shading devices were designed for different façades.

Figure 13 illustrates various transitional spaces designed for the targeted people and allowing various activities to take place.

Figure 13. Transitional Space and dimension of a typical unit

Figure 14 exemplifies how cross-ventilation can be achieved. The shading device is made of bamboo and is permeable, to allow wind penetration and heat dissipation. Occupants can adjust the angle of the shading device to control the sunlight and air movement flowing into the room.

Figure 14. Flexible shades and cross ventilation

The residential block is open at the ground level to encourage pedestrians' use of the courtyard as a public space (Figure 15). The orientation and shape of the openings encourage cooling winds. It was estimated that at the North entrance of the courtyard an average wind speed of 2m/s can be achieved; while elsewhere, except at the centre of the courtyard, the wind speed is predicted to be only 1m/s, Figure 16.

Physiologically equivalent temperature (PET) and PMV values were calculated with RayMan software (Matzarakis, 2014) for several scenarios, including summer morning and noon, Figures 17 and 18, respectively.

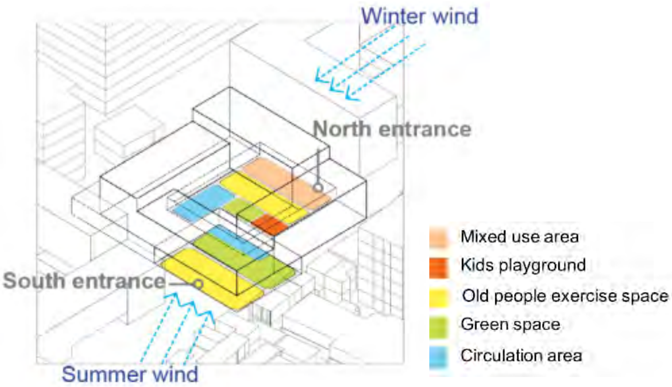

Figure 15. Courtyard design

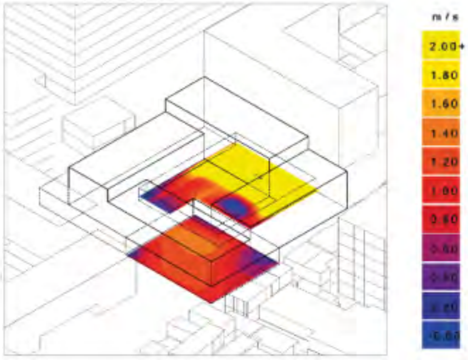

Figure 16. Wind simulation results (source: WinAir for Ecotect)

Figure 17. Typical summer day morning (7am, 22 July) (source: RayMan)

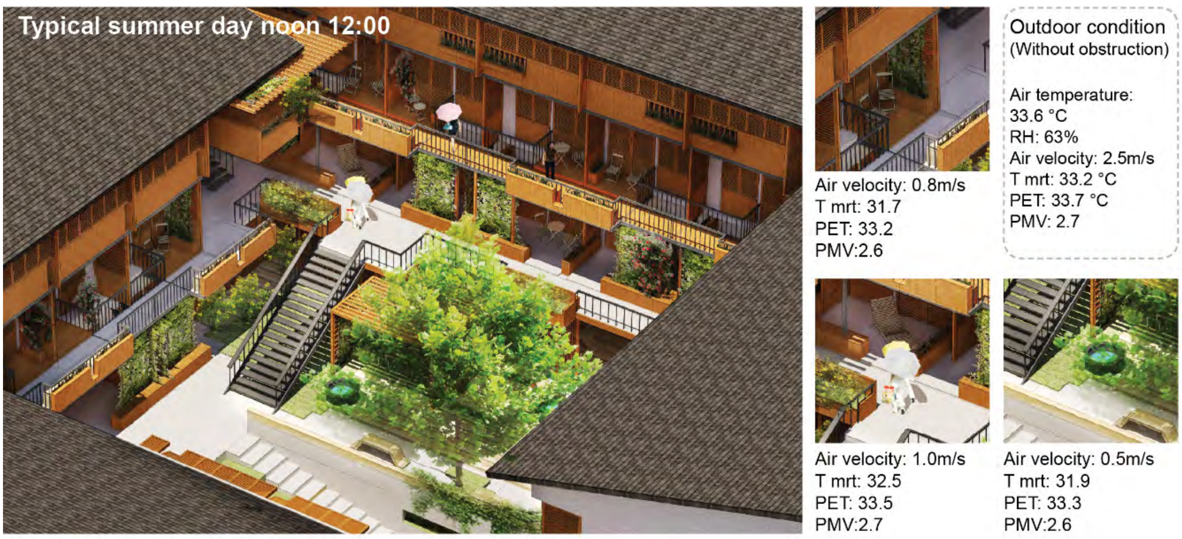

Figure 18. Typical summer day noon (12am, 22 July) (source: RayMan)

During the mild season, people can stay outdoors for almost the entire day, allowing many activities to be performed in the courtyard or in the balcony (terrace). Figure 19 illustrates possible activities and residents' adaptive behaviours (10:00 am, 22 March). The shades can be opened to allow sunlight and ventilation inside the room.

Figure 19. Typical mild season (10am, 22 March)

Conclusion

The study demonstrated that comfort is achievable in a free-running residential courtyard form urban block. The absence of air conditioning units hanging on the balconies further allowed the balcony to be a usable extended semi-outdoor space.

The proposed final design scheme incorporates the environmental strategies studied at the pre-design stage and during the design development. This includes several key decisions. Firstly, the provision of a movable and permeable shading device on the balcony to block both direct and diffuse solar radiation. Its permeability allows air movement through the semi-outdoor spaces and indoors, and its adaptability permits the user to control and adjust it according to the seasonal needs. The careful design of the courtyard form and the location of an opening to allow wind penetration helped creating a better microclimate, thus contributing to improving outdoor and indoor environmental conditions. While serving as an outdoor habitable space, the courtyard also offers residents a cohesive and vibrant place where they can socialise and enjoy community living.

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Optimization of building form to reduce insolation

Aram Yeretzian[1], Hmayag Partamian[2], Mayssa Dabaghi[3], Rabih Jabr[4]

[1] Department of ArD and CEE, SFEA, AUB, Beirut, Lebanon, aram.yeretzian@aub.edu.lb
[2] Department of ECE, SFEA, AUB, Beirut, Lebanon
[3] Department of CEE, SFEA, AUB, Beirut, Lebanon, mayssa.dabaghi@aub.edu.lb
[4] Department of ECE, SFEA, AUB, Beirut, Lebanon, rabih.jabr@aub.edu.lb

Abstract: The best way to save energy is not to need it. This paper will present the application of an optimization algorithm that assesses the degree of insolation in relation to architectural form. One of the key factors in achieving lower energy consumption in buildings is minimizing the heat gains due to incident solar radiation or insolation. This holds especially true for buildings within the Middle East and regions that share a similar climate with high levels of solar radiation. Upon inputting a project's latitude, allowable development areas and the dates when incident solar radiation on the building should be minimized, the optimization tool will generate and iterate through different building forms with the sole aim of minimizing insolation while satisfying the givens. Preliminary optimization results show that an optimized form could receive about 35% less solar radiation than a conventional building form (a rectangular prism). The development of this tool will enable design teams, during the early design stages, to make informed decisions that aim at having energy efficient buildings. In addition to this optimization, other parameters (such as adjacent buildings, resistance to wind and sloping sites) and window / wall ratios could eventually be integrated.

Keywords: Insolation, building form, optimization, energy efficiency.

Introduction

The growing world economy is coupled with increased energy usage in the domains of industry, buildings, transportation, agriculture, etc… (Sachs, 2015). In 2014, primary energy consumption had grown by 22% relative to the consumption in 2004 (Chen et al, 2017) which had already grown by 49% relative to that of 1984 (Perez-Lombard et al., 2008). In addition, energy-related greenhouse gas emissions account for over 80% of global anthropogenic emissions (Quadrelli et al, 2007). These figures are a cause of concern given that with the projected increase in the world population (United Nations, 2015) and the rapid rate of urbanization (UN-Habitat, 2016), energy consumption and its associated CO_2 emissions will continue to rise (UNEP, 2016). This will result in massive changes in climate (floods, droughts, extreme storms, crop failure, sea level rise, ocean acidification, etc.) (Perez-Lombard et al., 2008). Buildings contribute a substantial portion of the energy consumption worldwide. In fact, 36% of energy consumption is used in buildings, 27% of which goes into residential buildings (Elgendy, 2012). Therefore, optimizing building form to reduce insolation should be the first step in reducing the energy consumption of buildings and designing energy efficient buildings.

Vernacular architecture shows a clear relationship between the sun and buildings whereby the later were protected from the sunrays in summer and benefited from incident solar radiation (will be referred to as insolation throughout this paper) in winter. This concept was addressed by Socrates almost 2500 years ago. Socrates described how the relative movement of the sun could define the shape, form and construction of a building (Davor, 2015). Since then, numerous builders, architects and designers have studied and developed these issues and the results have ranged from different vernacular types (relating instinctively to the sun as per different geographical locations) to allowing for adequate solar access for individual buildings as well as groups of buildings or neighborhoods (Knowles, 1985).

Recently, numerous studies have addressed the reduction of energy consumption in buildings (Evins, 2013). There is research suggesting that the energy use of buildings can be reduced by adopting designs that are sensitive to the thermal performance of the building envelope, the proportion of the window and wall areas, the type of glazing, the efficiency of the mechanical systems, efficient construction systems, potential for renewable systems, etc. Although all of the strategies mentioned above are important, the 3 dimensional shape of a building has a significant impact on the reduction of energy use (Adamski, 2007). Areas that are subjected to high levels of insolation, can benefit significantly from building shapes that receive less insolation because the less the building receives solar radiation, the less it will have to cool the interior spaces.

A primary goal in the design of a building is to achieve thermal comfort for occupants within it. In parallel, the aim of the design should be to minimize energy expenditure to reduce both operation costs and environmental impact. Today, computers allow the design team the possibility and capability to analyze and evaluate the extent of solar access on a three-dimensional form. This can provide the team with useful information at the initial stages of the design process. For that purpose, this study aims to generate building shape based on optimizing insolation in order to assess the performance of the building geometry so that it is less reliant on energy (e.g. for cooling buildings in a hot climate).

Methods

This case study used an optimization algorithm that can take an initial predefined form with a set of constraints and iterate upon various options and geometric parameters, calculating the insolation upon the building for every iteration until the optimal form (minimum insolation) is reached.

Initial Parameters

The algorithm was applied on a hypothetical building at latitude 33.5°N (such as Beirut, Lebanon) where the weather is characterized as having mild winters and sub-tropical summers. The temperature profile for Beirut is shown in Figure 1 (UNDP, 2005).

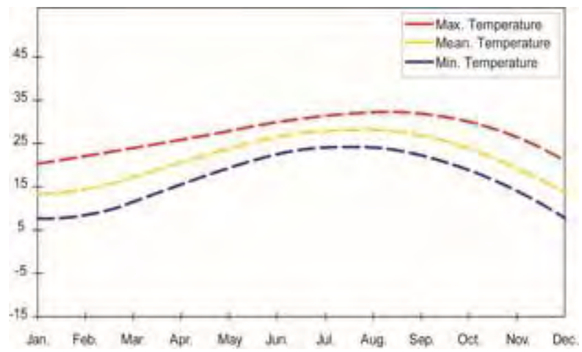

Figure 1: Monthly temperature fluctuations in Beirut

As a first step a two-dimensional rectangular shape was optimized using the algorithm. The date was set at June 21. This was followed by two optimizations for a three-dimensional form with the same built up area having 10 floors but with different roof configurations. In the first example the roof is horizontal (comparable with the initial rectangular solid shape) while in the second the algorithm was run to optimize the roof component also.

Optimization

The optimization algorithm used was developed by the research team (details provided elsewhere). It consisted of a nonlinear program which can be solved using popular solution algorithms including sequential quadratic programming, and more recently interior-point methods (MATLAB, 2017). In summary, this algorithm integrated information relative to the climate at a certain latitude and the building shape. It took into account the position of the sun relative to a shape, the intensity of radiation associated with the solar angle and the date for which the optimization was required.

Validation

A two-dimensional optimization was performed to validate the expected result.

Constraints

The approach governing the optimization process was such that the algorithm was free to manipulate the shape until reaching the desired outcome. Furthermore, in order to relate the study to contextual requirements, a number of constraints were defined namely, minimum usable area, maximum allowable area and maximum building height.

Output

The output provided both a shape that respected the built up area in terms of floor plan area and number of floors as well as the amount of insolation on the shape. This was useful in calculating the percentage reduction of insolation with respect to the initial shape.

Results

Two-dimensional optimization

The first step consists in optimizing a two-dimensional rectangular shape while keeping the total area of the horizontal surfaces constant. After inputting the initial geometry of the shape, the latitude of the location and the requirement of receiving minimal insolation on June 21, the optimization process results in a shape that has its long axis aligned with the East West orientation, as shown in Figure 2.

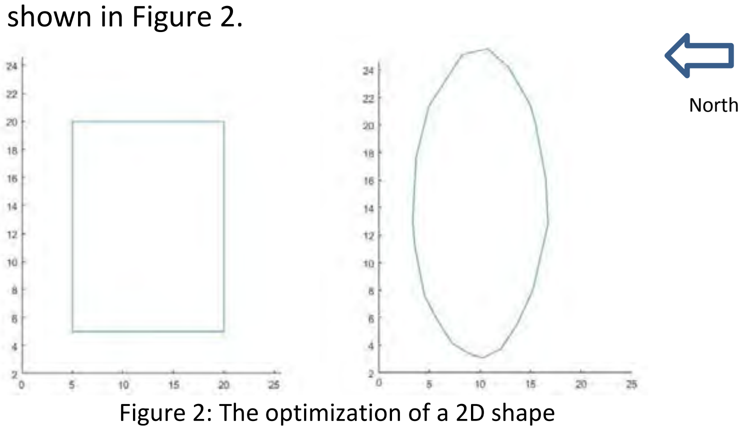

Figure 2: The optimization of a 2D shape

Three-dimensional optimization on June 21

The second step consists in optimizing a building shape that complies with the application of the allowable exploitation rights. This building shape, shown in Figure 3, is conventional in shape because there is no attempt to modify the geometry of the building from an energy efficiency perspective.

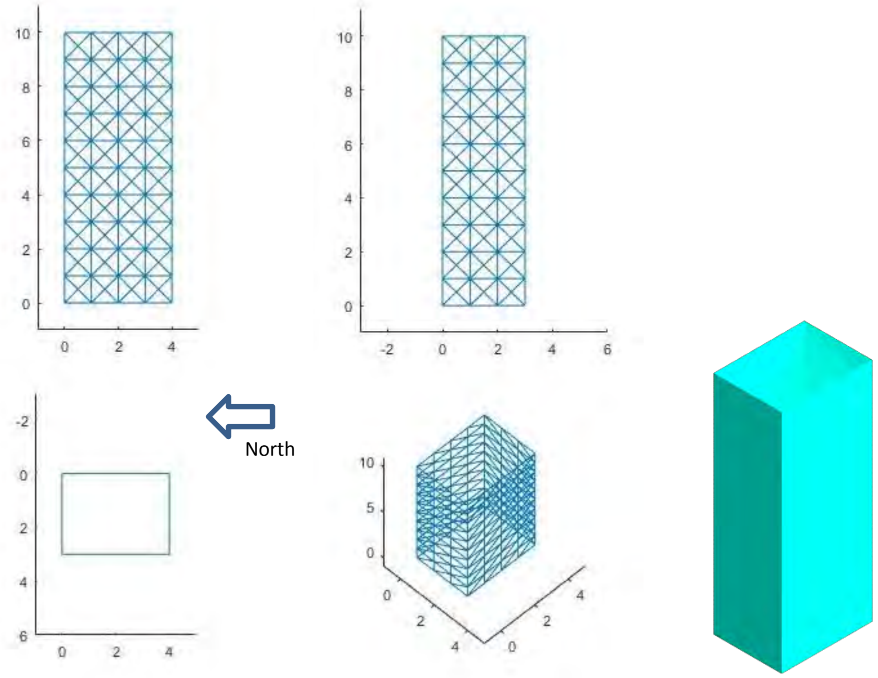

Figure 3: Initial 3 D building shape (complying with exploitation rights)

The total insolation on this building form on June 21 is 802 KW. The rendered shape on the right in figure 3 represents the initial form which is that of a rectangular solid like many of the buildings we see in Beirut city, shown in Figure 4.

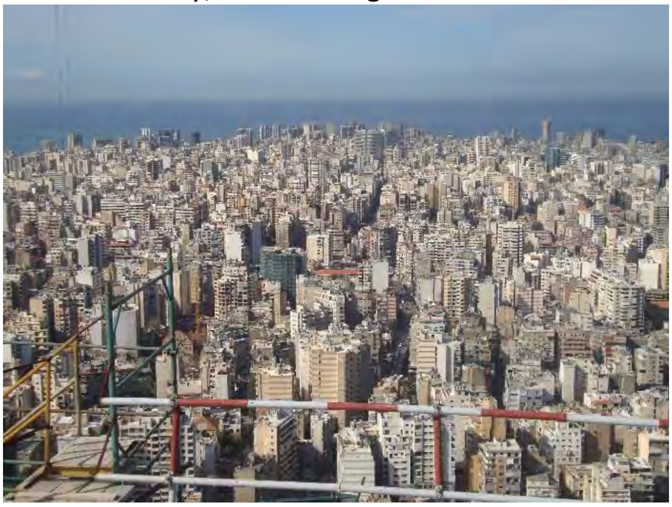

Figure 4: Buildings in Beirut

Three-dimensional optimization on June 21 (with a flat roof)

After specifying the latitude of the location and the date, the third step is to have the algorithm optimize the shape (leaving the roof component horizontal) so that the building envelope configuration receives the least amount of solar radiation on June 21. Therefore, the initial form – again a rectangular solid (Figure 3) - is optimized resulting in the shape shown in Figure 5. The optimized shape has a curved overall form with its long access oriented East-

West. The shape also tilts towards the South at an angle equal to that of the solar altitude at noon for the Latitude. In this case, the roof is maintained as flat due to the consideration that many buildings still locate numerous services on the roof. Therefore, having a flat roof would allow the proper installation of water tanks, mechanical cooling and heating machinery, receptors as well as, in some cases, an accessible planted green roof as an amenity for the building. Such a building typology requires that all the mechanical services would be located in a place other than the roof and the water system would be pressurized.

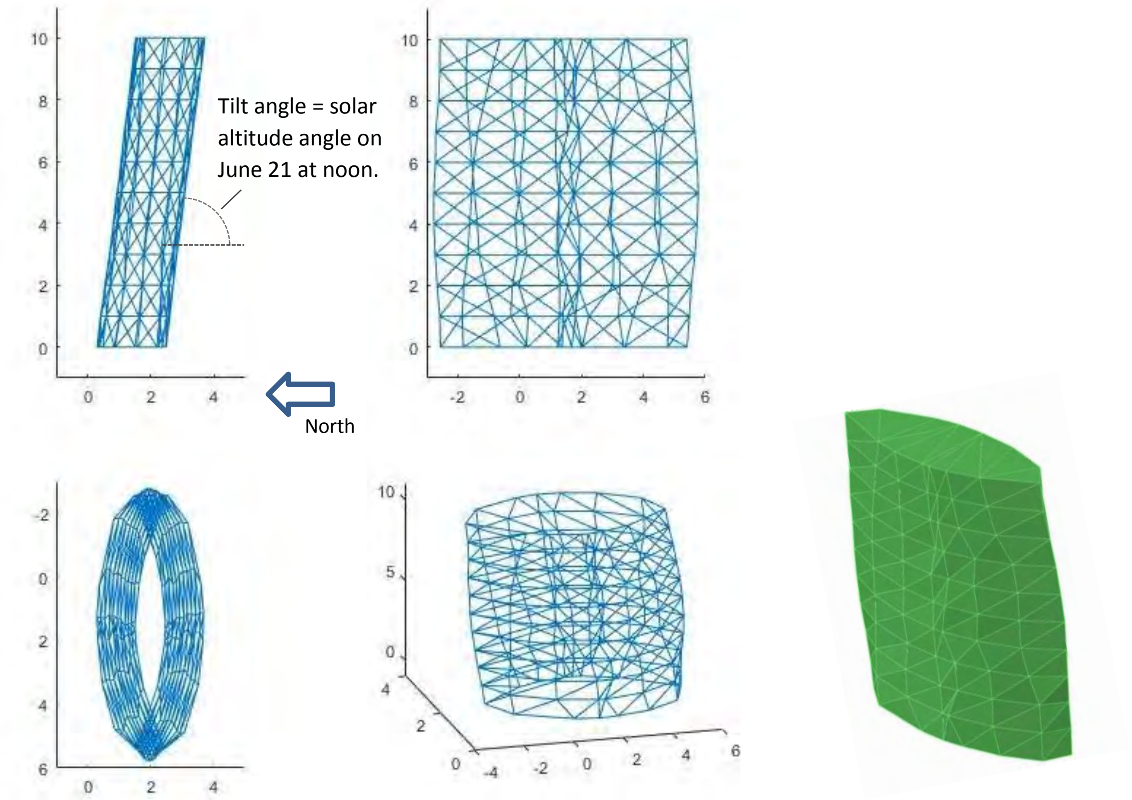

Figure 5: Building shape optimized for June 21

The initial insolation of 802 KW was reduced to 544 KW; a 32% reduction of insolation with respect to the initial shape.

Three-dimensional optimization on June 21 (with an optimized roof)

In this fourth step, the algorithm is run to optimize the initial building shape shown in Figure 3 to receive the least amount of insolation (on June 21) not only on the vertical surfaces but also on the roof (Figure 6). The initial inputs of latitude and exploitation rights remain unchanged. In this case, it is considered that the roof space is not used for particular services as mentioned previously, but can actually be integrated as interior space into the final level of the building – either as a penthouse, office space, common multi-functional space for the building or other.

The amount of incident solar radiation on this optimized form is 503 KW. This represents a 37% reduction when compared to the initial building shape shown in figure 3.

It is worth comparing the insolation on the elevations only since this could allow the analysis and evaluation of the form with varying numbers of floors. The design team can therefore assess the amount of incident solar radiation if a building is 1.5 or 2 times higher than the initial simulated building. Table 1 summarizes the results of the different optimizations.

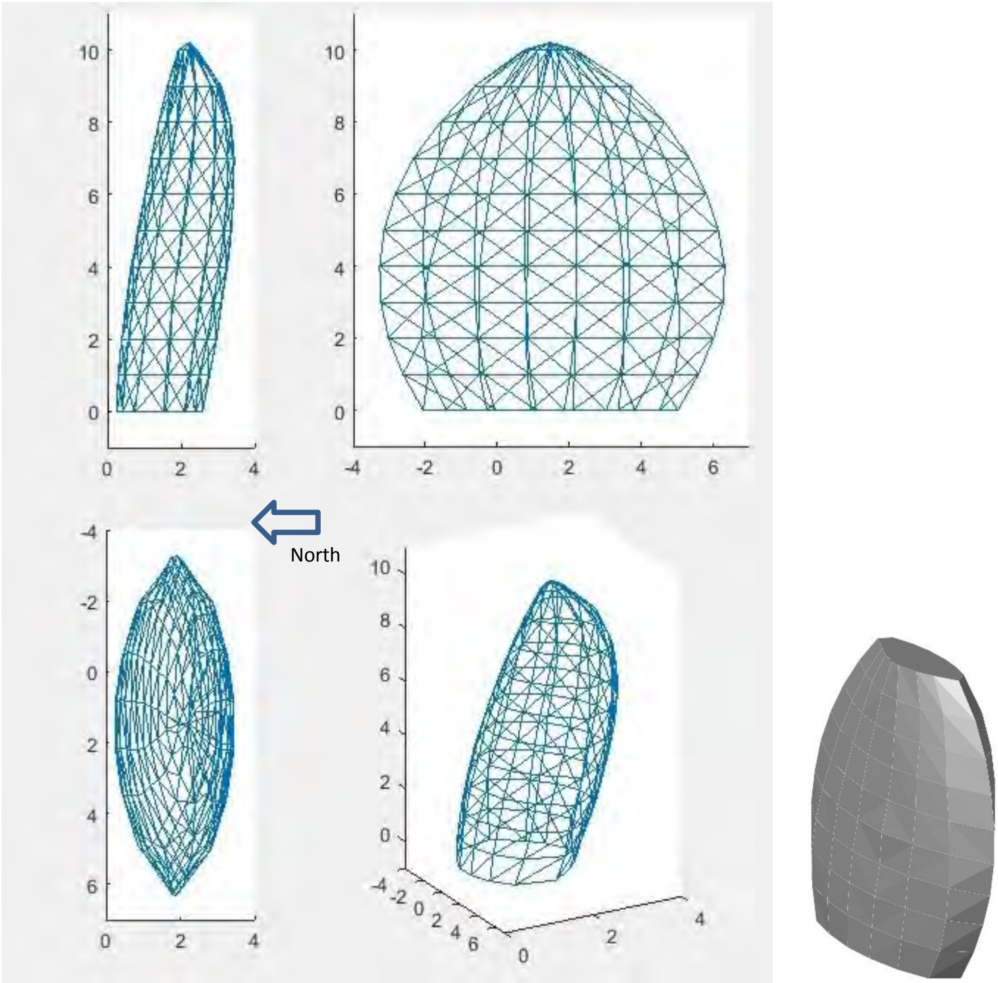

Figure 4: Optimization of the building form including the roof for June 21

Table 1: Comparative simulation results

Insolation	Shape excluding the roof		Shape including the roof		
	Initial rectangular shape	Optimized elevations	Initial rectangular shape	Optimized elevations only	Optimized elevations and roof
Value (KW)	602	344	802	544	503
Reduction (%)		43		32	37

Discussion

The algorithm optimizes the initial shape supplied by the researchers to reduce insolation during a given time frame. As presented in the results, the reduction in incident solar radiation, in both optimization runs, is considerable at 43 % (without an optimized roof) and 32 % (with an optimized roof) as shown in Table 1.

It is important to note that for comparison purposes, all the 3 shapes have the same number of floors and the same total built up area. Therefore, the developer will not lose any sellable area due to this optimization process. Moreover, one can input a constraint regarding the width of a building so that the efficiency of the floor plan, related to the building typology, is not compromised.

Building shape

The optimized building shape has a long access oriented East-West thus reducing the exposure of the East and West elevations. This is important as the elevations that are oriented towards the East and the West receive substantial amounts of insolation because of the low solar altitude angles. This, coupled with the high ambient temperatures during the day result in increased cooling loads to make the indoor spaces more comfortable. Also, the overall shape tilts towards the South thus shading itself from the high solar altitude angles during the midday.

The shape's tilt is equal to the solar altitude for the given context thus minimizing the intensity of insolation at noon as the solar rays are parallel to the shape. In addition, the optimized configuration of the building's rooftop significantly reduces the incident solar radiation as compared to the flat roof.

Strengths and Limitations

The strengths of this optimization process are:
First, the optimization algorithm is latitude specific rather than country specific. This suggests that this algorithm can be useful in analyzing the relationship between building shape and optimization as a function of latitudes. So, given the variations of the relative movement of the sun associated with different latitude degrees, interesting results are anticipated. Second, it should be noted that a similar approach could be used for buildings in cold climates where the desire is to optimize the building form to maximize solar heat gain, hence reducing heating loads. Third, the algorithm can be applied to a group of buildings (rather than just one building as presented in this paper) whereby the assessment of insolation can be evaluated while including the effect that adjacent buildings have on each other. Moreover, this will allow the study of insolation on outdoor areas between the buildings since the environmental conditions of these negative spaces between buildings is an important parameter that affects the thermal comfort sensation of pedestrians. This is important because if the space outside a building is shaded then the cooling load in a building is significantly reduced. Finally, this algorithm can be developed to process additional constraints as outlined in the section "Further work" below.

The limitations of this optimization process are:

First, within the framework of this study, the roof component remains excluded from the insolation calculations. Second, at this point, running the optimization is time consuming and does not really provide an interactive tool which is its intent. Therefore work needs to be done to reduce the time required for the calculations at each iteration to allow the design team to consider the results of the optimization and investigate different options.

Conclusion

Presently, buildings have rectangular solid shapes whose energy efficiency is enhanced by the design team to reduce the solar loads by manipulating the thermal transmittance of the building envelop components and mechanical systems.

Rather than designing buildings with a conventional approach, optimizing building shapes to reduce insolation in the building will change the design process to include the possibilities of design investigations that will help conceive buildings whose shape receives less solar energy. After testing, investigating and assessing this shape, the design team can either study other options (such as reducing the number of floors and increasing the floor area), or can develop this shape further. This development could be in identifying the envelope configuration (continuous with different window wall ratios, loggias, balconies, etc.) to further re-assess the impact of solar radiation on the building shape. It is understood that the site should allow for some massing flexibility in order to allow taking full advantage of the results. In other words, if the site restricts the investigation of the building shape, then the full potential of this tool would be compromised.

Further work

Once the limitations of the optimization process are resolved, the next steps would consist of including constraints pertaining to site limit and site setbacks, resistance to wind load as per applicable codes, sites having a slope (with a particular orientation). In addition, adding the following constraints to the algorithm would render the outcome more comprehensive:

First, the "buildability" of the three dimensional form can be addressed by having the components of the envelope’s triangular mesh equal to a specific dimension (e.g. 90 cms).

Second, the ability to indicate balcony and / or loggia components can be very informative because their spatial configurations and orientations could have a considerable impact on reducing incident solar radiation.

Third, further modelling would include the distribution and location of fenestration according to respective orientations and incident angles of insolation. The "window /wall ratio" of the envelope would be studied as per the amount of solar radiation that enters the space - considering that it is an open floor plan with an identified core. The amount of solar rays that directly impact the internal horizontal and vertical surfaces would be assessed.

In conclusion, further development of this algorithm can be instrumental in informing the thinking process of design teams aiming to align their projects with global initiatives and targets to reduce energy consumption in buildings and cities.

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Design to Thrive

Effect of External Shading Blinds Provision on the Energy Consumption and Visual Comfort

Zhang Yi[1] Huang Qiong[1], Zhang Anxiao[1]

[1] School of Architecture, Tianjin University, Tianjin, China, email@kclara1017@163.com

Abstract: External shading blinds, which operates directly with daylight, has close relationship with energy consumption and comfort of building. As a double-edged sword, external shading blinds can optimize cooling energy consumption in summer and increase heating energy consumption in winter, reduce the possibility of discomfort glare and decrease essential illumination on working face. Therefore, the selection of external shading blinds should satisfy multi-dimensional objective of energy consumption and comfort considering both of its advantage and disadvantage. In this paper, an office model in cold climate region of China is used for exploring the influence mechanism of external shading blinds by computer simulation and subjective experiments. The variables are the direction, width and angle of blinds. The targets are low energy consumption and high visual comfort. By a graphical optimization method, the results summarize the influence mechanism of the variables, explain the incomplete coincidence between variable interval and target requirement, tries to ascertain the balance point for multiple target orientation, and enhances practical significance. In the process of architectural design, architect should adjust the weight ratio of each target according to the different needs of building in order to assist design decision.

Keywords: External Shading Blinds, Cold Climate Region of China, Energy Consumption, Visual Comfort

Introduction

Daylight is an indispensable element for human survival. Suitable daylight into indoor will improve working efficiency and ensure physical and psychological comfort. However, excessive daylighting will increase solar heat gain and augment cooling consumption, with the easy occurrence of disturbing glare. External shading blinds are considered to be an effective way to reduce energy consumption and improve comfort, by keeping daylight out and reducing the amount of light and energy by solar radiation into the room. In addition, external shading blinds can be used in both new buildings and retrofit projects.

Single objective optimization of a building component is found frequently in literature. Examples include obtaining high visual performance or lower energy consumption. Some studies proved that external shading blinds can help decrease cooling consumption, with increasing lighting consumption in the areas with adequate solar radiation. It would reduce total consumption, if appropriate form of external shading blinds were chosen.

Other studies tried to demonstrate that external shading blinds are an ideal way to eliminate glare and make use of daylight, with illumination and glare into comfortable range for written and computer operation. Architectural design is a comprehensive job to consider a variety of issues and balance multiple actors. As a decision-making tool, multi-objective optimization technique has been used to determine the best solution. Since architectural design is to consider simultaneously multiple objectives in an almost infinite number of possible design solutions, the form of external shading blinds should be chosen by multi-objective optimization techniques. And it will provide a new angle for green building design. The results will be used for elevation design.

Visual and energy evaluation criteria

Examples of evaluations for energy and visual aspects.

At the early stage of research, the contradiction of energy consumption and visual comfort was mentioned. An example is a study that focuses on the difference of light environment and monitoring energy consumption with shading fabrics and shading blinds for different façades. Another example is about light environment and thermal comfort by combination of different forms of shading blinds and window size. However, low energy consumption and high visual comfort are not the focus of the studies.

An in-depth examination of different forms of external shading blinds shows that the integration of louver shading devices in building leads to comfortable indoor thermal conditions and might lead to significant energy savings, by comparison with that of the building without shading devices. Energy requirements for a building in cool and hot seasons are quantified for different window and louver areas under the climatic conditions of five cities at different latitude through simulations using TRNSYS software. In this study, different directions and angles of blinds are discussed, but without visual comfort.

Simultaneous optimization for low energy and visual comfort for window size was made. Whole-building computer simulations were performed on a standardized office located in a temperate climate. This work aims at determining the suitability of combined optimization criteria on window sizing procedures for low energy consumption with high visual comfort and performance. A series of energy and visual criteria were selected.

Energy and visual performance evaluation criteria

Energy performance criteria

The evaluation standard of energy consumption is based on the quantitative analysis of the energy consumption of different equipment. Energy consumption can be divided into cooling consumption, heating consumption, ventilation consumption, lighting energy consumption and equipment consumption. They can be expressed in terms of energy units (kWh or GJ) per unit area per time unit. Typical goal is to select the least energy consumption system, which is in accordance with local regulations on temperature. User comfort can also be used for evaluating energy performance, but it is not used universally with little evaluation indexes of thermal comfort in different climate areas.

Visual performance and comfort criteria

Some studies noted that discomfort due to visual effects is reported more frequently than discomfort due to thermal effects, because discomfort by visual effects, like glare, headaches, deregulation of circadian rhythm leading to depression, is more immediate and real-time. Therefore, the evaluation of visual effects is important and assignable in building design due to the possible rejection by users of the built environment.

The evaluation of visual comfort can be divided into static light environment evaluation and dynamic light environment evaluation. Static light environment evaluation is based on static image brightness and optical index data for a certain time point of daylighting and artificial lighting. The illuminance-based and glare-based criteria of static one are Daylight Factor (DF) and Daylight Glare Index (DGI). Dynamic light environment evaluation is based on the dynamic change of indoor light environment for 8760 hours in a year. And the illuminance-based and glare-based criteria of dynamic one are Daylight Autonomy (DA) and Daylight Glare Potential (DGP).

Evaluation method used

Location and climate type description

The computer model was evaluated for the climate of Tianjin, China (39°N, 117°E) using the CSWD file. According to Chinese standards, Tianjin belongs to Cold Region and Class Ⅲ Daylight Climate Zone. Average winter temperature for the locale range is between -10°C and 0°C, average summer temperature between 18°C and 28°C, and annual average illuminance is between 35klx and 40klx, with buildings here having heat-preservation in winter and heat-proofing in summer. North China, part of northeast China and northwest China are in the same zone region as Tianjin. And it is also described in the Köppen climate classification as Dwa Climate Region. It characterizes hot summer and dry winter.

Test room description

In order to highlight how different optimization criterion affects solution space, the module consists of a hypothetical office room (dimensions being 6.0m*6.0m*5.0m) is based on the size of the office room in China. There is a single external wall, which can exchange energy with the outside through windows (dimensions being 5.5m * 2.0m), but other walls, roof and floor are of insulation values. Based on GB50189-2015 and GB50033-2013, which are China standard, glazing in windows is double 6mmpane clear with 13mm Argon gas interlayer (U-value 2.511 W/m2 K, SHGC 0.697), the external wall is Lightweight concrete block poly insulation & plasterboard (U-value 0.464), and the reflectance of wall, roof and floor is 0.6, 0.8 and 0.3 respectively.

The west façade and south façade were chosen to be the external wall, which has great influence on indoor environment in Cold Region. The variables are the direction, width and angle of the shading blinds (Figure 1). The horizontal blinds were selected for south façade with no-shading and overhangs as reference, and the horizontal blinds and vertical blinds were selected for west façade with no-shading as reference. Besides that, the width of the blinds is 100mm, 200 mm, 300 mm or 600mm, which is used in buildings in China, and the angle of the blinds is 0°, 15°, 30°, 45°, 60° or 75°(0° blinds are the minimum shading of external wall and window and are perpendicular to the wall; 90° blinds are the maximum shading of external wall and widow and are parallel to the wall). The control methods of blinds angle are divided into fixed methods and manual methods. Manual control of the external shading blinds can be adjusted according to season, time, weather or other factors. Usually, the angle of blinds is adjusted to cut off daylight in summer when solar radiation is strong, and the blinds are opened to guarantee indoor illumination and temperature at the end of summer. However, it is very subjective to manually control the blinds. Therefore, it is very effective and convenient to adjust the angle of blinds twice a year. In one year temperature change is after the change of solar altitude. So the time needed for shading measures does not correspond exactly to summer. It needs shading measures when outdoor temperature is above 29°C, and total solar radiation is above 280W/m2. The time of shading stage for the west façade and the south façade is from April 16th to September 24th, and the time of no-shading stage is from September 25th to April 15th next year.

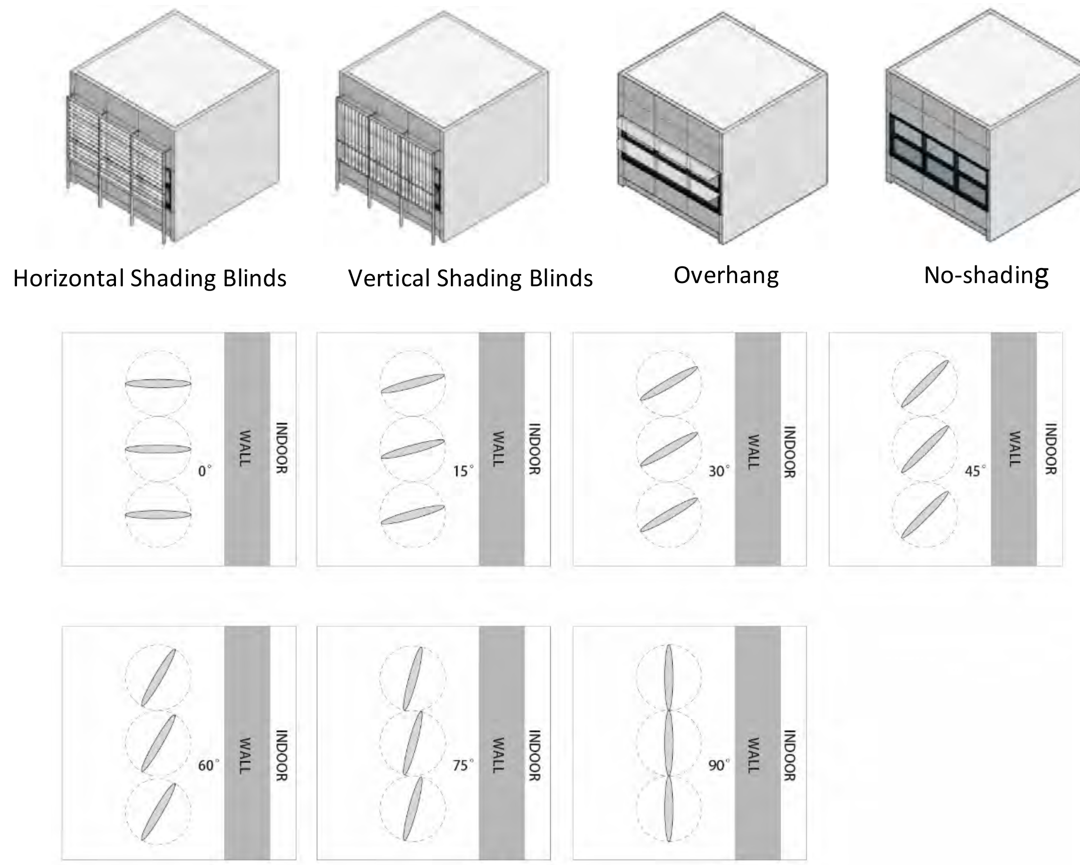

Figure 1 Measured energy consumption and visual comfort of all the studied forms of shading blinds with different directions and angels

Evaluation criteria

Energy consumption evaluation benchmark is minimal total consumption, which includes heating, cooling and artificial lighting consumption simulated by the software Design Builder.

Daylight Autonomy (DA) and Daylight Glare Potential (DGP) were chosen as quantitative indicators for visual aspect. Dynamic light environment is simulated by the software Daysim. The DA threshold in the following analysis was assumed to be 500 lux, which was approximated from the IES lighting handbook. The DA for most of the sensors resulted in above 50% means, and that in more than 50% of all the daylight time occupants will be able to fulfill tasks that require 500 lux using daylight. And more than 80% sensors with DA over 50% means that the space is bright enough for the needs of users in most daytime of a year. DGP above 0.40 means the degree of perceived glare is disturbing or intolerable, and the space dazzles for users. More than 80% of all the daylight time with DPG under 0.40 means the glare of the space is perceptible or imperceptible in most daytime of a year.

In conclusion, the evaluation criteria of energy consumption and visual comfort are as Table 1.

Table 1 Summary of criteria being tested

Type of aspect	Criteria	Dynamic evaluation of acceptance value
Energy	Total consumption	Least energy consumption of the studies case based on building codes
Visual	Area DA exceeds 50% Hours DGP below 0.4	80% of total area of office room occupancy 80% of total time during office occupancy

Simulation results and discussion

According to the results, the direction and angle of the blinds have significant influence on energy consumption and visual comfort, but the influence of the width of the blinds is insignificant. Therefore, take200mm-width blinds as example, the influence mechanism of different direction and angle of blinds on energy consumption and comfort was analyzed.

The results show that, there are different forms of external shading between the lowest energy consumption and the highest visual comfort, and the forms of illuminance-based criteria and glare-based criteria are inconsistent. Therefore, to select a form of external shading blinds, not only reducing energy consumption should be taken into account, high visual comfort should also be satisfied (Table 2).

Table 2 The forms of shading blinds for energy consumption and visual comfort

	West façade		South façade
	Horizontal blinds	Vertical blinds	Horizontal blinds
Energy Consumption	Fixed 0-30° Shading Stage 15° No-shading Stage 0°	Fixed 0-60° Shading Stage 45° No-shading Stage 0°	Fixed 0-15° Shading Stage 0° No-shading Stage 0°
Illuminance-based Criteria	Fixed 0-15° Shading Stage 0-45° No-shading Stage 0-30°	Fixed 0-30° Shading Stage 0-30° No-shading Stage 0-30°	Fixed 0-30° Shading Stage 0-30° No-shading Stage 0-30°
Glare-based Criteria	Fixed 45-90° Shading Stage 30-90° No-shading Stage 30-90°	Fixed 45-90° Shading Stage 45-90° No-shading Stage 30-90°	Fixed 45-90° Shading Stage 15-90° No-shading Stage 45-90°

In order to meet practical needs of multi-objective, the data of energy consumption and visual comfort can be synthetically considered, with the assumption that all of the objectives are of equal importance. If the objectives cannot be taken into account, they should be satisfied as much as possible, and the importance is as follows: energy consumption ≥ illumination-based criteria ≥ glare-based criteria.

Under fixed control, for west façade, the angle of horizontal blinds should be 30 °, the angle of vertical ones should be 45°,and the angle of horizontal blinds for south façade should be 45° (Figure 2).

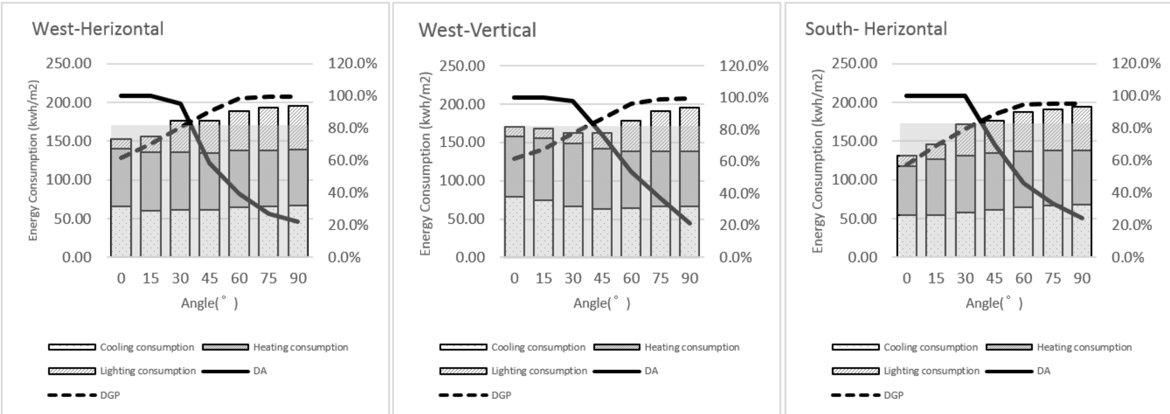

Figure 2 Solution space for energy use and visual performance and comfort of shading blinds with fixed control

Under manual control, the angles of horizontal blinds for west façade at shading stage is 45°, and that at no-shading stage is 0°. The angel of vertical blinds for west façade at shading stage is 45°, and that at no-shading stage is 30°. The angel of horizontal blinds for south façade at shading stage and no-shading stage are 15° (Figure 3).

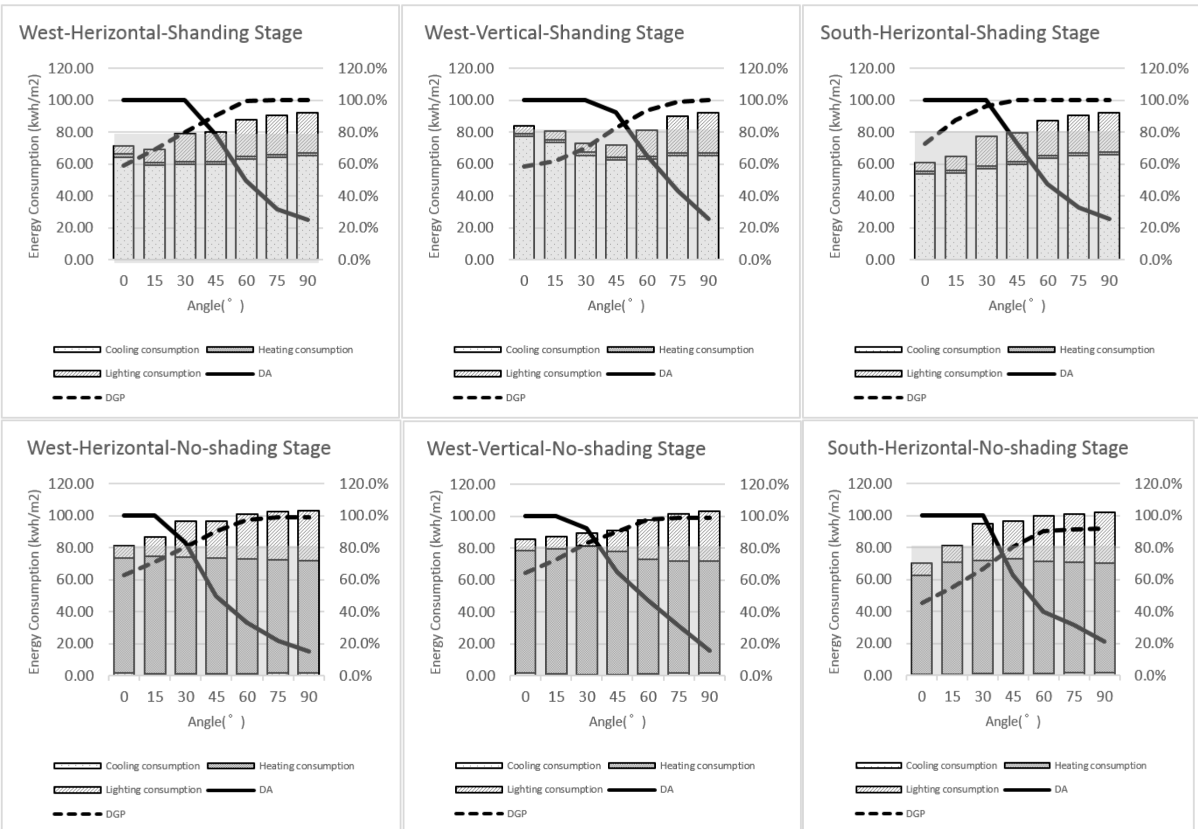

Figure 3 Solution space for energy use and visual performance and comfort of shading blinds with manual control

The results provide a reference basis for the selection of external shading blinds of one climate type. The prototype already has high-performance elements optimized for energy savings. Therefore, it allows us to optimize external shading blinds only. The results show that it will cause great problems to focus on energy saving without high visual comfort in some cases, because of the difficulties to meet the varied requirements of users. Therefore, combined with climate characteristics, the form of external shading blinds for high comfort and low energy consumption should be considered in design and update process. Optimized building design requires specialists working together.

Conclusions

The influence of external shading blinds on indoor environment is various, and the result of multi-objective optimization techniques combined with energy consumption and comfort was provided in this study. In the process of building design and construction, the weight of each objective is different. In the case that one objective is prior than others, it is significant to balance the proportion of them on the basis of the sole objective during the research and design. This sort of weight division is also the focused issue in the future. The weight division of multi-objective optimization is the focus in future. And the evaluation standard of visual comfort is more than DA and DGP. Besides, architecture design is comprehensive, multi-factored and multi-objective. When selecting the form of external shading blinds, other objectives should be considered, including overall effect, construction cost, maintenance cost, etc. With technology development, new forms of shading blinds will continue to bring forth new ideas to solve the contradiction between low energy consumption and high visual comfort. In this study, only the common form of external shading blinds was involved. With the invention of new products, further study of new form should be focused on.

Acknowledgements

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Passive Architecture in Very Hot Climate: a Simple and Flexible Bioclimatic Approach for Architects

Ferran Yusta-Garcia[1], Catherine Semidor[1] and Denis Bruneau[2]

[1] GRECCAU, Ecole d'Architecture et de Paysage de Bordeaux, France,
ferran.yusta@bordeaux.archi.fr
[2] I2M, UMR 5295, Université de Bordeaux, France, denis.bruneau@u-bordeaux.fr

Abstract: The last 25 years have been ground-breaking in architectural design on low energy consumption in cold climate, mainly in north-western cultures. For an architect today, the method to design a passive house in cold weather and the choice of the Architectural Actions (AA), are clearly established. When the question comes to how to build a passive house in warmer, hot, and very hot climates, the strategies are poor and often results of a combination of western strategies with a local relook. From several visits in Middle East countries, Saudi Arabia, UAE, Oman, Palestine, Qatar, we concluded that the strategy for low consumption houses is not established yet and poorly grasped. The lack of training on low energy consumption in hot climate and the low price of energy, force designers and owners to relay on over usage of air-conditioning systems as measures to catch up on poor bioclimatic design. This paper proposes a new approach on bioclimatic design for hot climates from an architect point of view. It is based on a Cooling Degrees Days approach, a state of art of contemporary architecture and professional experience. Local climates are classified according to passive strategies: cold/cold, cold/cool, temperate/temperate, cold/hot, warm/hot, and hot/hot.

Keywords: Hot climate architecture, early design stage, passive architecture, low energy consumption architecture, cooling degrees day method.

Introduction

The low energy consumption tendency and know-how in hot climate countries is awakening from a dark period on high energy dependency, even though still much work is to be developed and promoted: methodologies, tools, labels, training... etc. Today more than 80% of people in the world live under a warm-hot climate, and millions of them under very hot climate, and so far in recent and modern construction, buildings follow a model of architecture called "international" with little efforts on architectural principles for low energy consumption. Finally the comfort is achieved relying on technical equipment, including air conditioning with high energy consumption.

Today, the international comfort standards cannot avoid the massif use of air conditioning systems, and its omnipresence and over-use has become a fact in the everyday life of the middle class in developed or emerging countries in hot climates. However in hot climate, like in cold climate, we find extreme contexts, countries that have shortages of access to electricity as some cities in Palestine or many countries in Africa and those who have an important energy access situation, as in Saudi Arabia or the United Arab Emirates. Paradoxically in both cases reach the low energy consumption is now a priority in national strategies for different reasons: one is designed to minimize the energy shortage, while rich countries aim to reduce exorbitant spending on subsidies in energy sold at prices below the cost of production for reasons of social solidarity.

In this paper we aim to explore a simple method for architects to produce well founded architectural solutions which could help to improve the comfort and the future quality of life of low-income families in hot climates combining a passive thinking but high flexibility on design without neglecting the use of newest construction technologies.

“Very hot climate” definition for designers.

The term "hot climate" is often too general in western and European cultures. Wladimir Köppen defined "hot desert climate" as Bwh, where “B” meant a climate defined by little precipitation, “W” indicating an extreme arid one with annual precipitation under a certain threshold, and “h” meaning low latitude climate with temperatures average annual temperature above 18ºC, which basically means hot arid weather. This term covers all Saharan Africa, Arabia, south of the United States and the center zone of Australia. However In this classification not all countries undergo the same need to use air conditioning, specially the countries of the Arabian Peninsula and around the Red Sea and the Persian Gulf, where record-breaking temperatures are often measured. In 2004 the ASHRAE and IECC (International Energy Conservation Code) agreed to create a common classification more accurate, standard 90.1.: Zone 1: very hot and wet (1A)/very hot and dry (1B). A climate is rated 1B "very hot and dry climate" if it has more than 5000 Cooling Degree Days (CDD) at a temperature of 10ºC.

By this method, the city of Riyad with 6026 CCD at 10ºC would be largely in this category. However with the same criteria, a city like Karachi in Pakistan with 6119CDD to 10ºC would be in the same category of hot climate even if it does not represent a climate as severe as the climate of the cities of the Arabian Peninsula. A higher temperature threshold would be more judicious to establish criteria to classify cities in extreme desert climates.

Table 1. Classification of cities based on their COOLING DEGREE DAYS at 26ºC

Celsius-based 2-year-average (2014 to 2015) cooling degree days for a base temperature of 26,0C in airports															Source www.degreedays.net
CDD 26ºC			Year	Month											
			TOTAL	J	F	M	A	M	J	Jl	A	S	O	N	D
EUROPE	FRANCE	NICE	40	0	0	0	0	0	3	23	13	1	0	0	0
		PARIS	29	0	0	0	0	0	5	16	8	0	0	0	0
	SPAIN	SEVILLA	305	0	0	1	4	35	54	99	84	21	6	0	1
		MADRID	253	0	0	0	0	12	44	108	71	17	1	0	0
	GREECE	ATHENES	293	0	0	0	0	8	40	97	108	38	2	0	0
MIDDLE EAST	SAUDI ARABIA	RIYADH	1630	1	6	22	102	218	272	327	326	223	123	10	0
		DJEDDAH	1509	21	28	61	99	159	177	240	261	198	154	76	35
		MEDINAH	2061	6	16	64	136	249	314	333	392	322	189	34	6
		MAKKAH	2324	44	59	115	182	271	308	340	338	290	221	104	52
	UAE	DUBAI	1769	1	12	26	100	221	259	334	339	249	179	45	4
	IRAN	ANWAZH	1840	0	1	8	85	232	340	402	388	266	115	3	0
	OMAN	MASCATE	1541	0	14	18	144	272	283	248	197	180	143	40	2
		SALALAH	586	3	6	25	70	118	117	26	15	48	80	57	21
	PALESTINE	NABLUS	156	0	0	0	5	17	19	28	50	29	8	0	0
		JERICHO	1102	0	2	16	55	123	158	228	259	174	76	10	1
	ISRAEL	JERUSALEM	315	0	1	3	11	29	31	59	93	66	19	3	0
AFRICA	SUDAN	KHARTOUM	2056	45	76	167	215	294	292	231	173	204	220	100	39
	CHAD	N'DJAMENA	1543	53	100	191	219	254	206	108	53	73	133	113	40
	NIGER	AGADEZ	2008	28	64	139	212	298	322	240	170	214	214	92	15
		NIAMEY	1776	58	104	190	249	270	224	128	81	111	188	130	43
AMERICA	USA	PHOENIX	1222	0	3	20	41	99	263	287	263	178	64	4	0
ASIA	INDIA	NAGPUR	1154	8	35	93	187	284	192	88	65	64	75	44	19
	PAKISTAN	KARACHI	1035	2	8	43	108	152	193	143	107	109	110	50	10
OCEANIA	AUSTRALIA	ALICE SPRINGS	658	108	99	90	23	3	0	0	3	18	88	112	114

If we consider that heat discomfort starts at 26º, under relative humidity conditions around 50%, and most of the air conditioning equipment starts also at 26º, then CDD26º is a good reference to classify the “hunger” for energy on active cooling of a climate. The choice of 26ºC is an arbitrary one and it depends on cultures and lifestyles. Cultural and social factors can have strong influence on the accepted “hot temperature” that we will not study in this paper.

Based on this method, Table 1 shows a classification on cooling energy needs based on a start of the cooling needs at 26º (considering that most of the existing air conditioning systems do not consider relative humidity parameters). It is clear that the GCC countries (Saudi Arabia, UAE…) are way far ahead on cooling needs that any other zone in the world.

Classification of a city climate by using the concept of “Climatic Seasons”

The approach of the climate of a city by a designer is not systematic and it is frequently neglected in projects of private houses and small collectives. In order to classify a site from the point of view of bioclimatic strategy we defined three simple situations that represent the broad majority of cases, and imply very different bioclimatic design strategies. These generic situations are described as follows:

Situation 1 - It is cold outside, and the vector [temperature, humidity] is unpleasant: users prefer to close doors and windows and reduce exchange with the outside. They try to get as much as possible of sun inside of the house.

Situation 2 - It is temperate outside, cool or warm, the vector [temperature, humidity] is pleasant: users prefer to open doors and windows to generate cross ventilation.

Situation 3 – It is hot outside; the vector [temperature, humidity] is unpleasant: users prefer to close doors and windows and reduce exchange with the outside. The sun-rays are blocked as much as possible.

Several of these three situations can arrive during one same day, making appear different day-types: 1-1, 1-2-3, 1-2, 2-3, and 1-3. The designer will then need a passive strategy for different day-type. The impression of cold, cool, warm and hot, can vary a lot depending on cultures. We chose the most usual range in Europe of 19ºC to 26ºC, but it could be adapted to any culture. With this range of comfort temperature and these three situations, we define a new concept named “CLIMATIC SEASON”, which are periods that can last several months with the passive strategy remains the same (fig.1)

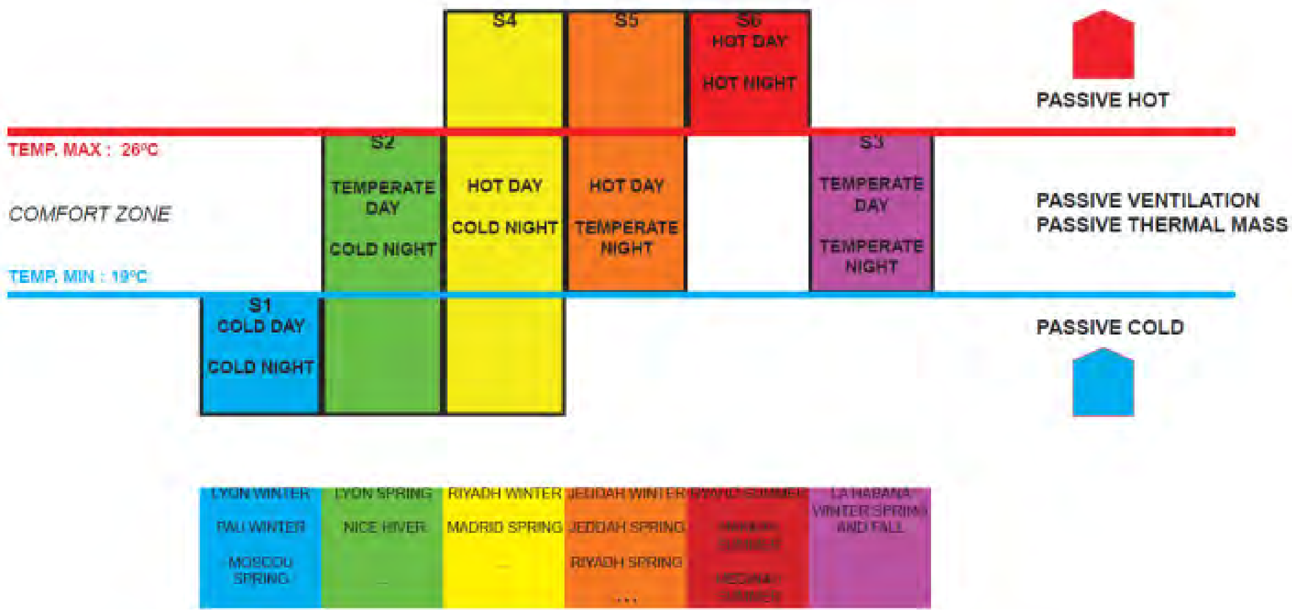


Figure 1. Diagram of “climatic seasons” with some examples of cities and their seasons.

These “climatic seasons” are defined as follows:

Climatic Season S1: cold days and cold nights. This season is the coldest of all, and it is characteristic of many cities in Northern Europe during winter. The temperatures are low, and even though they may not be extreme they are permanently under the cold temperature threshold. People do not want to have exchanges with the exterior.

*Climatic Season S2: cool days and cold nights.*This season combines daily temperatures that are comfortable and night temperatures that are below the comfort threshold.

Climatic Season S3: temperate days and nights. This season is always comfortable in terms of temperature, because the maximum temperature and minimum daily remain always within the thresholds of comfort. These conditions are often associated with tropical cities close to the sea with high relative humidity values and a low daily temperature fluctuation.

Climatic Season S4: hot days and cold nights. Daily maximum temperatures are above the upper threshold of comfort and the daily minimum temperatures are below the low threshold of comfort. An important part of the day temperatures are comfortable but at peak hours we either feel too hot or too cold.

Climatic Season S5: hot days and warm nights. Daily maximum temperatures are above the upper threshold of comfort and daily minimum temperatures stay in the range of comfort. A large part of the day exterior conditions are uncomfortable and late in the evening they become confortable for some hours.

Climatic Season S6: hot days and hot nights. This is the hottest season of all, temperatures are high all the time, and even though they may not be extreme they are permanently over the high threshold of comfort temperature. It is characteristic of many cities in the Middle East during spring, summer and fall.

Degrees-days for architectural passive strategy

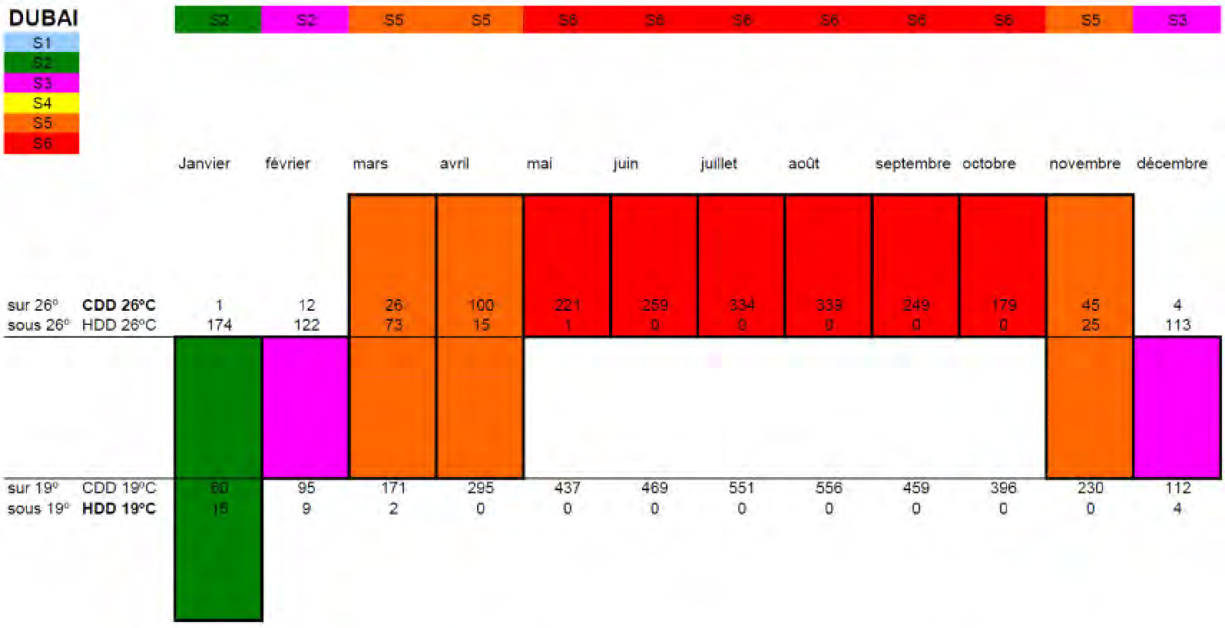
To be able to organize the year of a city in Climatic Seasons we will use a widespread and relatively accessible index in all the bibliographies and websites: the heating degree-day (HDD) and cooling degree-day (CDD). We will use two values associated with the high temperature threshold of 26ºC: HDD26 and CDD26, and two values associated with the low temperature threshold of 19ºC: HDD19 and CDD19.

In order to determine to which Climatic Season (S1, S2,... S6) belongs a particular month of the year of a city, we need to establish criteria based on a established threshold:

Season 1: HDD19>0 CDD19=0 heating- no air conditioning- no exterior
Season 2: HDD19>0 CDD26=0 heating- no air conditioning- some exterior
Season 3: HDD19=0 CDD26=0 no heating- no air conditioning- lots of exterior
Season 4: HDD19>0 CDD26>0 heating- air conditioning- some exterior
Season 5: HDD19=0 CDD26>0 no heating- air conditioning- some exterior
Season 6: HDD26=0 CDD26>0 no heating- air conditioning- no exterior

However we need to allow a certain overtaking on these values to dismiss extreme values: it will be enough in a very cold day (S1) with an outside temperature of one degree over the comfort level to consider it as a temperate-cold season (S2). To allow this over threshold we will use a percentage of the “monthly comfort allowance”, MCA, representing the total degree-day located between the comfort thermal range. For a 7º degrees range the MCA value is 217, for a 31-days month, 210 for a 30-days month and 196 for the 28-days month. We will consider that if the DD value divided by MCA is less than 5%, it will be consider as 0 in terms of Climatic Seasons classification.

Figure 2 shows the comparison between the Climatic Season classification and the maximum and minimum daily temperatures of a average journey in Dubai in 2005 climate data, the result shows that from May to October the temperatures are too high to open the windows at night time, as shows the Season 6 with the “Climatic Season” method. In January, the temperatures are low, especially at night time, so a Season 2 strategy can be carried out.



jours par mois	31	28	31	30	31	30	31	31	30	31	30	31
Somme DD	217	196	216	210	217	210	217	217	210	217	210	217
somme DD/jours mois	7,0	7,0	7,0	7,0	7,0	7,0	7,0	7,0	7,0	7,0	7,0	7,0
CDD26/Somme DD	0,5%	6,1%	12,0%	47,6%	101,8%	123,3%	153,9%	156,2%	118,6%	82,5%	21,4%	1,8%
HDD26/Somme DD	80,2%	62,2%	33,8%	7,1%	0,5%	0,0%	0,0%	0,0%	0,0%	0,0%	11,9%	52,1%
CDD19/Somme DD	27,6%	48,5%	79,2%	140,5%	201,4%	223,3%	253,9%	256,2%	218,6%	182,5%	109,5%	51,6%
DD/Somme DD	7,4%	4,6%	0,9%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	1,8%
date 2005	14/1	18/2	16/3	9/4	18/5	10/6	13/7	8/8	13/9	15/10	17/11	14/12
Temp max	23	25	27	32	35	42	45	45	41	37	30	27
Hum min	53%	34%	42%	31%	22%	14%	11%	12%	15%	27%	20%	28%
Temp min	16	16	23	22	25	32	34	34	30	28	23	19
Hum max	82%	82%	83%	64%	54%	59%	59%	34%	70%	66%	65%	64%

Figure 2. Comparison of Climatic Season method with a temperature-humidity values of 2005 for Dubai.

The climatic year

The combination of the Climatic Seasons of a particular city over a year is named 'Climatic Year', the diagram in figure 3 shows all the different combinations of climatic seasons for different cities. These combinations allow us to define several types of Climatic Years:

-Temperate cold Climatic Year: S1 + S2 + S4 (Paris, Bordeaux)
-Temperate hot Climatic Year: S1 + S2 + S4 + S5 (Madrid, Valencia, Sevilla, Jericho)
-Very hot and dry Climatic Year: S2 + S4 + S5 + S6 (Riyad, Medinah)
-Very hot and humid Climatic Year: S2 + S3 + S5 + S6 (Dubai) and S2 + S5 + S6 (Doha)
-Extreme hot Climatic Year: S5 + S6 (Jeddah, Makkah)

Architectural strategy based on Climatic Seasons

Both, hot/cold, bioclimatic strategies have similar approaches organized in five general axes:

1-External hot/cold protection

2-Inner heat management
3-Heat evacuation/capture
4-Cold/heat production
5-Heat/cold adaptation

PARIS	S1	S1	S1	S1	S1	S2	S4	S2	S2	S1	S1	S1
BORDEAUX	S1	S1	S1	S2	S2	S4	S4	S4	S2	S2	S1	S1
MADRID	S1	S1	S1	S2	S4	S4	S5	S5	S4	S2	S1	S1
JERICHO	S1	S1	S2	S2	S4	S5	S5	S5	S5	S4	S1	S1
VALENCIA	S1	S1	S2	S2	S2	S5	S5	S5	S5	S2	S2	S1
SEVILLA	S1	S1	S2	S2	S4	S5	S5	S5	S5	S2	S2	S1
RIYAHD	S2	S2	S4	S5	S6	S6	S6	S6	S6	S5	S2	S2
DOHA	S2	S2	S5	S5	S6	S6	S6	S6	S6	S6	S5	S2
DUBAI	S2	S3	S5	S5	S6	S6	S6	S6	S6	S6	S5	S3
DJEDDAH	S5	S5	S5	S5	S6	S6	S6	S6	S6	S6	S5	S5
MEDINAH	S2	S4	S5	S6	S6	S6	S6	S6	S6	S6	S5	S2
MAKKAH	S5	S5	S5	S6	S6	S6	S6	S6	S6	S6	S5	S5

Figure 3. Climatic year of different cities by combination of climatic seasons

Once a site is classified in Climatic Seasons, we must combine (fig.4) Architectural Actions to clearly define the spirit of the passive strategy for each Climatic Season. An Architectural Action is a decision taken by the designer having an impact on the architectural shape of the building to bring down the energy consumption of the building,

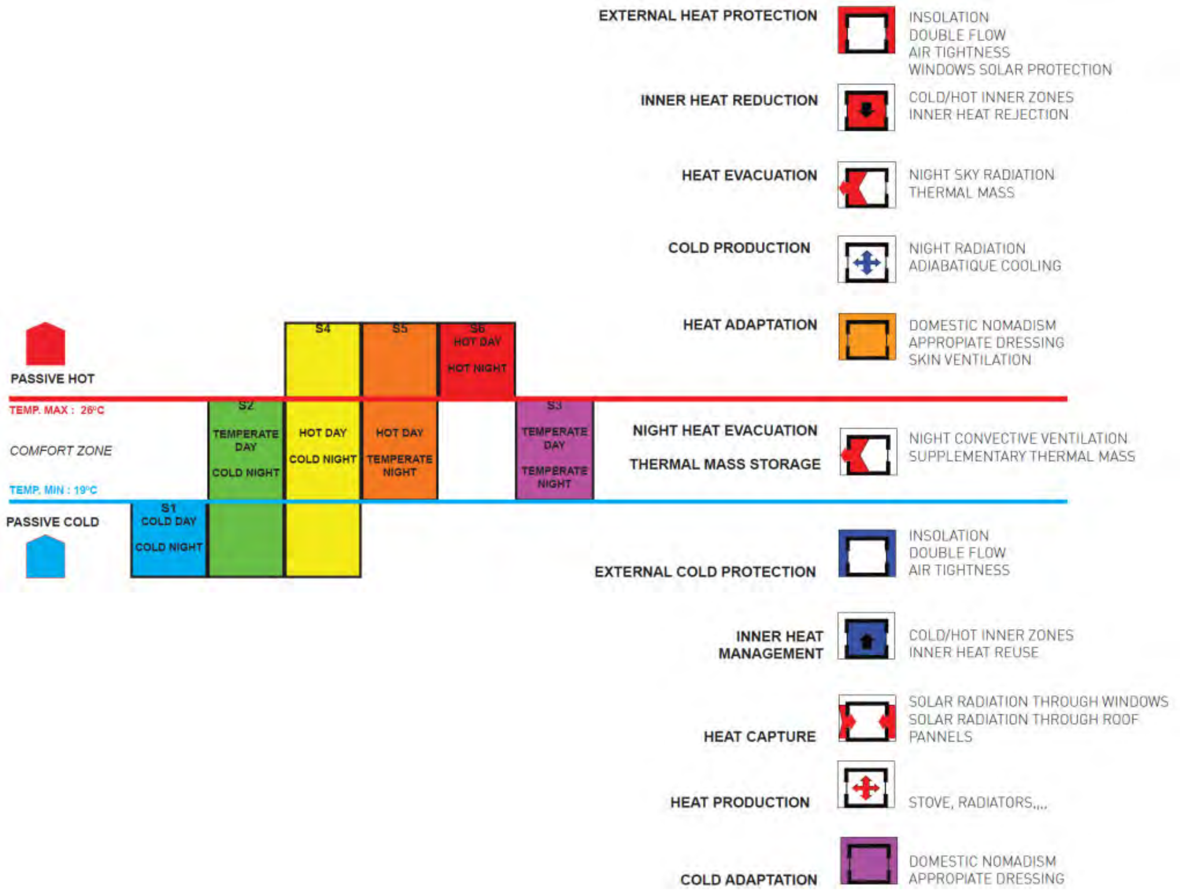


Figure 4. Strategic directions and the most common architectural actions

Classification of architectural Actions (AA) for a very hot climate

We classified all the Architectural Actions extracted from the scientific literature of the last 50 years and real practice in contemporary construction under hot climates fig.6. They are grouped by five main axes, and several sub-groups:

AXIS 1: External hot protection

1. Heat reduction coming through glazed openings in housing: Reduction of glass surface exposed to the sun. Reduction of the surface of glass-not-exposed-to-the-sun. Preferably N-S orientation. External brise-soleils. Inner opaque curtains. 2. Heat reduction coming through the opaque parts: Strong thermal insulation. No thermal bridges. Low emissivity on exterior walls. Ventilated double skin. Albedo reduction by peripheral shading. 3. Reduce the heat entering the house through ventilation: high-performance air sealing. Double flow thermal exchanger. Partial cooling of the air by underground pipes.

AXIS 2: Inner heat reduction

1. Energy efficiency label, position and management of the cooking appliances in the kitchen, thermal zoning of the area of the kitchen that produces a strong residual heat (fire and oven). Specific air extraction in areas with strong heat production. 2. Energy efficiency label of the computers, small appliances and lighting. Electrical switches for complete disconnection of appliances out of charging periods. 3. Position and management of domestic hot water in the bathroom and distribution: Extraction of water steam with strong latent heat storage.

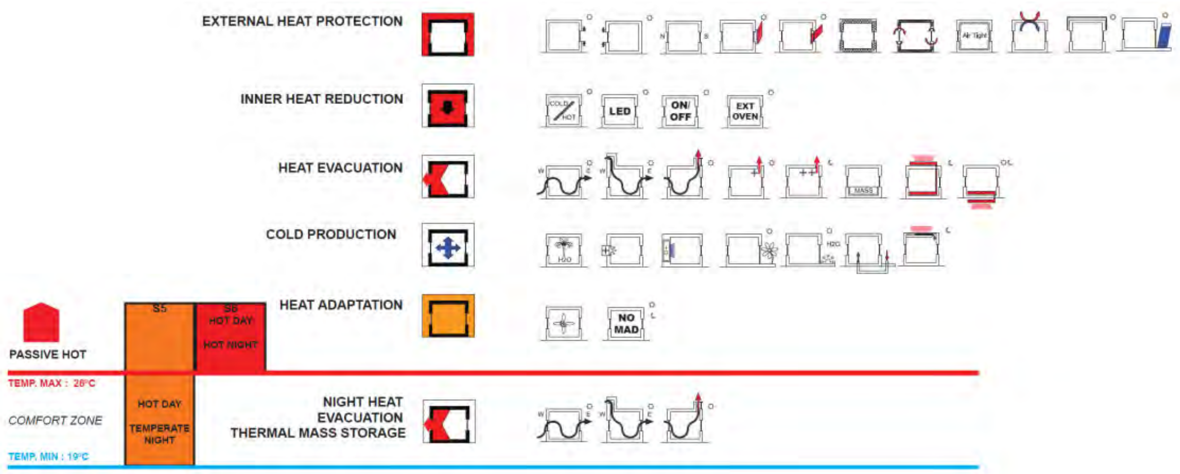


Figure 6. Architectural Actions associated to a very hot climate year as Jeddah or Makkah

AXIS 3: Inner heat evacuation

1 - Convective Evacuation by air: natural cross-ventilation air currents. Wind catcher towers. Thermic gradient towers or walls. 2. Night radiant heat discharge of thermal load by the facades and roof with specific thermal mass storage. 3. Heat storage in the thermal mass of the building. Delete ground insulation to facilitate the evacuation of heat to the ground.

AXIS 4: Cold production

1 - Adiabatic cooling: Direct or indirect adiabatic cooling. 2. Radiant night sky cooling with specific thermal mass storage. 3. Night recovery of the lower temperature air under radiant plate orientated towards the sky.

AXIS 5: Heat adaptation

This axis is to identify all architectural, social and cultural elements that can improve the comfort, without involving measures that change the inner temperature:

1 - Facilitate the natural mechanisms of regulation of the human body: no air-conditioned mechanical ventilation, fans.

2. The use of space: nomadism inside and outside.

3. Wearing appropriate clothing that helps other measures to work well.

Discussion

This simple method can be carried out by anyone having a low internet connection to get the degrees-day data, a simple worksheet program, and some basic principles on bioclimatic architecture. Thus, any young designer can understand the main bioclimatic challenges of a project site and propose a solid bioclimatic based project to their clients. However, the choice of an Architectural Action is associated with logic of investment and a pay-back period, which is associated with three factors: 1. The contribution of the Architectural Action to decrease the energy consumption. 2. The cost of construction and maintenance over the years of the Architectural Action. 3. The price of energy. The first and second factors, the energy saving and the price of the action will depend on climate and the geographical context of the site. According to local context, energy prices and the construction cost will depend on factors such as the hourly cost of labor, the lack of access to electricity, the cost of building materials. The combination of these values must create a hierarchy in the possible Architectural Actions based on the pay-back period of each that will invite the designer and clients to implement it or not

To quantify these parameters we modeled on Design Builder model with a hot climate house-type, and created a digital model by different architectural action variants. We quantified the influence of each action per day. In parallel we have evaluated the additional cost of each one of these actions on the cost of construction of the House. These elements define the payback period in function of the electricity cost and allow a hierarchy on the choice according to local context.

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Design to Thrive

Full-scale experiment on energy-saving modifications for urban houses in hot-humid climate of Malaysia

Mohd Azuan Zakaria[1,2], Tetsu Kubota[1], Doris Hooi Chyee Toe[3] and Mohd Hamdan Ahmad[3]

[1]Graduate School for International Development and Cooperation, Hiroshima University, Higashi-Hiroshima, Japan.
[2]Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, Johor, Malaysia
[3]Faculty of Built Environment, Universiti Teknologi Malaysia, Skudai, Johor Bahru, Malaysia.

Abstract: This study investigates the effects of proposed energy-saving modifications for urban houses in hot-humid climate of Malaysia through full-scale experiment. The effects of the proposed modifications were investigated under the two different cooling strategies, i.e. structural cooling strategy (night ventilation) and comfort ventilation strategy (full-day ventilation). Then, the thermal comfort level of indoor spaces with the proposed modifications is evaluated based on operative temperature (OT) and SET* indices. The results show that the resultant indoor air temperatures of the master bedroom were successfully reduced by the structural cooling strategy during day and night after the application of the proposed modification strategies. Meanwhile, the reduction could only be seen during the night-time in comfort ventilation. It was found that the application of attic fan at night did not contribute in lowering the nocturnal air temperature in the master bedroom. The evaluation of thermal comfort shows that the indoor condition of master bedroom with the proposed modifications in comfort ventilation strategy was found to be preferable for hot-humid climate of Malaysia when the evaporative heat loss was taken into consideration.

Keywords: Passive cooling, Energy-saving, Natural ventilation, Hot-humid climate, Modification

Introduction

Energy consumption for space cooling in buildings has been increasing rapidly especially in the warm, developing regions such as Southeast Asia. Due to the rapid economic growth and urbanization, the energy demand in this region has increased more than 50% between 2000 and 2013 (IEA, 2015). In Malaysia, for example, it has been reported that the number of households having air-conditioner has increased about sixth-fold during the last two decades (1990-2010) (Mahlia et al, 2004). Therefore, passive cooling should be considered wherever possible to reduce the energy demand caused by the growing use of air-conditioning. Passive cooling in the building scale can be divided into two methods, i.e., 1) removing indoor heat by natural ventilation and 2) blocking the heat entering the building by solar radiation controls and heat transmission through building envelopes (Lee et al, 2017).

Natural ventilation is a basic technique for creating a comfort indoor climate and for reducing the cooling load of the building. Natural ventilation strategies that are commonly suggested for building in hot-humid climate is night ventilation and full-day ventilation. Night ventilation (or structural cooling) is based on the circulation of the cool ambient air to decrease both the temperature of the building's structure and the indoor air (Santamouris et al.,2010). According to Kubota et al., the application of night-ventilation in the urban terraced house in Malaysia could provide better thermal comfort for the occupants in term of operative temperature compared to the other ventilation strategies (Kubota et al., 2009). In the study of Jamaludin et al., the application of night ventilation was also found to be the most effective natural ventilation techniques for residential college building due to lower mean temperature values compared to other ventilation strategies (Jamaludin et al., 2014). However, when the night ventilation is adopted in a hot-humid climate (windows are closed during daytime), relative humidity tends to be high during the daytime, though the air temperature is reduced (Kubota et al., 2009). Meanwhile, full-day ventilation (or comfort ventilation) is a common method for achieving indoor thermal comfort in a hot-humid climate especially for the lightweight building. However, Givoni has demonstrated that continuously ventilated thermal mass can significantly lower indoor maximum temperature (Givoni, 1994). Wang and Wong investigated the impacts of various ventilation strategies and façade design on indoor thermal environment for naturally ventilated apartments in Singapore (Wang and Wong, 2007). In term of natural ventilation approach, they concluded better indoor thermal comfort can be achieved by the application of full-day ventilation than the other ventilation strategies. In general, by full-day ventilation, indoor air temperature would be increased with the increases of indoor wind speed but with a lower humidity level. Based on the reviews, though there are two different approaches of natural ventilation in the tropics, the most effective ventilation strategy that can provide better thermal comfort and indoor air quality is still uncertain.

Meanwhile, there are various strategies for solar radiation control and building's thermal modulation such as shading devices, building insulation, increasing of the reflectance of building's material and the application of high thermal mass structure (Lee et al, 2017; Gupta and Tiwari, 2016; Santy et al, 2017). The strategy of heat reduction for the roof is also important in the hot humid climate since the main thermal energy absorbed for habitable space is due to the heat fluxes crosses the roof (Givoni, 1994). Recent studies showed that the solar radiation control for the roof can be achieved by the implementation of reflective and radiative approaches in roofing systems (Obaidi et al, 2014), green roofs (Mahmoud et al., 2017) and hydrodynamic cool roof system with energy recovery (Chávez et al., 2016). However, most of these studies have been conducted in laboratory settings or to be applied with air-conditioning system. The scientific studies on the effects of the above-mentioned strategies to improve thermal performance of buildings under natural ventilation condition remain few especially by night and full-day ventilation strategy.

Therefore, the objective of this paper is to investigate the performance of passive cooling modification strategies under natural ventilation strategies of night and full-day ventilation by full-scale field measurement in the experimental houses. The aim of this study is to develop the comprehensive energy-saving modification techniques through passive cooling for existing urban houses in Malaysia.

Full-scale experimental houses in UTM campus

The full-scale experimental houses (two adjacent terraced houses) were constructed in the main campus of *Universiti Teknologi Malaysia* (UTM), in the city of Johor Bahru (1°29'N 103°44'E) in December 2015 (Figure 1). The experimental houses were designed to represent typical floor plans of Malaysian terraced houses. Each of the houses measure approximately 6.7 m by 9.8 m with a total floor area of 127 m^2. Meanwhile, the height of each floor is 3.1 m from the floor to ceiling. As shown, the building is oriented towards North. Each house has two master bedrooms on the first floor, facing North and South, respectively. The ground floor consists of living hall, dining hall and kitchen.

The houses are constructed of brick and concrete and had single glazing windows. In addition to the original plans, small slit windows were added onto the upper and lower parts of the main windows, partition walls, and doors. Moreover, exhaust fans were installed in the attic spaces, master bedrooms and staircase halls for experiments. The houses are not insulated except for both end walls that were insulated to eliminate the thermal influences from the outdoors.

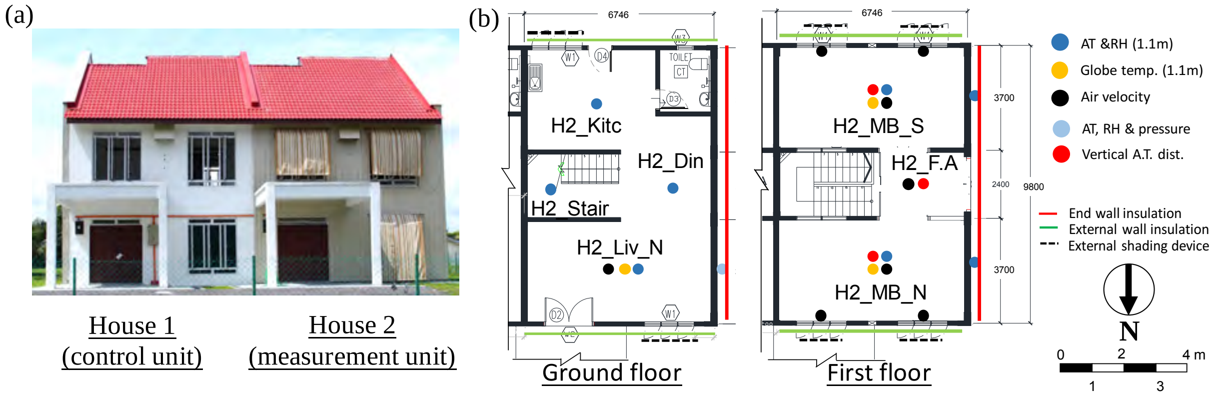

Figure 1. Energy-saving experimental houses in UTM campus. (a) Front view (b) Floor plans of the experimental houses. H2: House 2, MB: Master bedrooms, N: North, S: South, F. A: Family area, Liv_N: Living hall on North side. Din=Dining; Kitc=Kitchen; Stair=Staircase

Methods: Full-scale experiment

The full-scale experiment was conducted in two units of the above-mentioned experimental houses from June to September 2016. In the field measurement, one of the houses (House 2) was equipped with the proposed modifications (i.e. measurement unit), while the other house (House 1) was remained unchanged as a control unit. The proposed modifications include i) roof insulation, ii) external wall insulation (outside), iii) external shading devices, and iv) forced ventilation (for the whole house and for attic spaces). To be noted that the modifications were selected based on the results of previous study that examine the optimum combinations of the modification techniques for the urban houses through numerical simulations by using TRNSYS and COMIS (Kubota et al, 2017). Roof insulation was installed underneath the roof board of north- and south-facing master bedrooms of House 2. Meanwhile, the external wall insulation was installed on the outer surfaces of the external wall of the master bedrooms. Both insulations were of 100 mm thick rock wool form with a thermal resistance of 3 (m^2K)/W. Furthermore, the external shading devices were installed on all windows in House 2 except for the window located in the washroom. The shading factor was set to be 0.75. The windows were shaded during the daytime (8:00-20:00) and unshaded during the night-time (20:00-08:00). As for the forced ventilation, a large exhaust fan was utilized at 30 air change rate per hour (ACH) for the entire house, while the attic fan was at 40 ACH. Both of the forced ventilation were applied only during the night-time to reinforce the effect of night ventilation (structural cooling).

The main variables for the thermal comfort assessment were measured in the master bedrooms (first floor) of the two units at 1.1 m above the floor. The measured variables were air temperature, relative humidity, wind speed and globe temperature. In addition, air temperature and relative humidity were measured in the attic spaces and at the other spaces located on the ground floor, i.e., dining halls, kitchens and staircases of both units. The outdoor weather data were recorded by a weather station located in an open space approximately 40 m away from the units. The conditions for the experimental cases (Cases 1-6) are described in Table 1.

Table 1. Study cases

Study cases	Natural ventilation	House 1 (control)	House 2
Case 1	Night ventilation	• Opening: All windows • Techniques: No	• Opening: All windows • Techniques: Building insulation + external shading
Case 2	Night ventilation	• Opening: All windows • Techniques: No	• Opening: All windows • Techniques: Building insulation + external shading + whole house fan
Case 3	Night ventilation	• Opening: Main windows • Techniques: No	• Opening: Slit windows • Techniques: Building insulation+ external shading + whole house fan + attic fan
Case 4	Full-day ventilation	• Opening: All windows • Techniques: No	• Opening: All windows • Techniques: Building insulation + external shading
Case 5	Full-day ventilation	• Opening: Main windows • Techniques: No	• Opening: Main windows (day)/ slit windows (night) • Techniques: Building insulation + external shading + whole house fan
Case 6	Full-day ventilation	• Opening: Main windows • Techniques: No	• Opening: Main windows (day)/ slit windows (night) • Techniques: Building insulation+ external shading + whole house fan + attic fan

Results and discussion

Effects of proposed modifications in structural cooling (night ventilation)

From this section on, we compare the results of measurement unit (House 2) with that of control unit (House 1) in terms of indoor thermal environments in the master bedrooms. Figure 2 shows the temporal variations of measured air temperatures and relative humidity (RH) in Cases 1-3 that analyze the effects of proposed modifications under the night ventilation condition (see Table 1). As shown, the outdoor air temperature during the measurement period ranges from 23.8-34.5°C, while the corresponding RH ranges from 50-100%.

Case 1 shows the effect of roof insulation, external wall insulation (outside) and external shading (Figure 2a). As shown, the air temperature of the master bedroom of the measurement unit (House 2) was lower than the control unit (House 1) by approximately 0.5-0.8°C during daytime. Meanwhile, there was almost no air temperature reduction during the night-time. This is simply because all of the above three techniques are effective in reducing the effect of direct solar radiation on the building during daytime. The RH in both rooms is almost the same, ranging from 70-90% during daytime and about 80-90% during the night-time.

In Case 2, the whole house ventilation was adopted at night in addition to the above-mentioned three techniques (Figure 2b). As a result, the air temperature reduction can be seen not only during the daytime but also during night-time. The air temperature reduction by the modifications is about 0.8°C during the day and night-time. This indicates that the application of the whole house ventilation is effective in reducing nocturnal air temperature, but the resulting indoor temperatures are still higher than the outdoors by about 2°C. Furthermore, the RH in House 2 is found to be increased accordingly after the modifications by approximately 3% compared with that of House 1 for the whole day.

In Case 3, the attic ventilation was applied at night in addition to all the techniques of Case 2. As shown in Figure 2c, the air temperature of the master bedroom in House 2 is lower by up to 1.4°C during daytime and night-time compared with those of House 1. The air temperature reduction was slightly larger than the previous two cases. However, it should be noted that the maximum and minimum outdoor air temperature were slightly lower than that of Case 2. In this case, the RH level was always higher than the control unit by about 6-7% during the whole day.

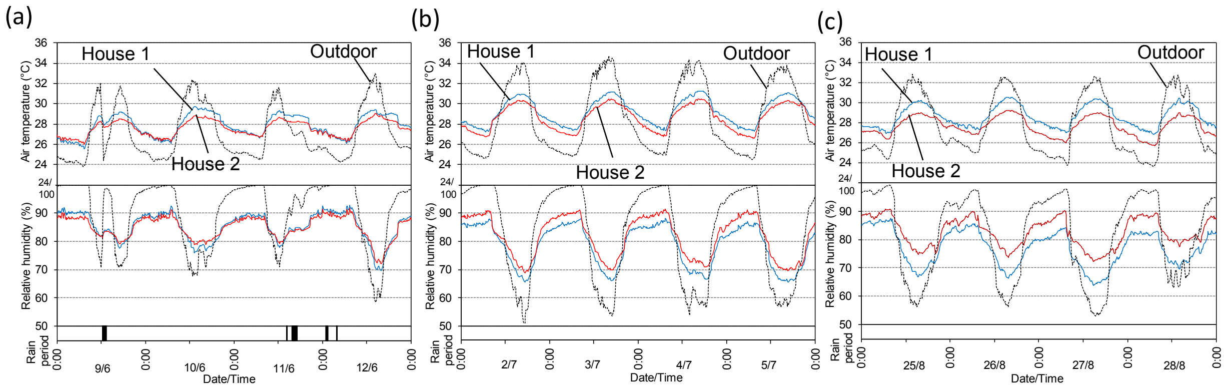

Figure 2. Temporal variations of air temperatures and RH in the master bedrooms of House 1 (H1_MB_S) and House 2 (H2_MB_S). (a) Case 1 (b) Case 2 (c) Case 3.

Effects of proposed modifications in comfort ventilation (full-day ventilation)

The same experimental cases were conducted under the full-day ventilation condition. Figure 3 shows the temporal variations of air temperatures and RH in the master bedrooms in Cases 4-6. As shown, the outdoor air temperature during the measurement period ranges from 23.0-34.0°C, while the corresponding RH ranges from 50-100%.

In Case 4 in which roof insulation, external wall insulation and external shading were applied, it was found that almost no air temperature reduction observed in the master bedroom of House 2 at daytime (Figure 3a). This is simply because the inflow of warm air into the room. Meanwhile, the nocturnal air temperatures were increased by about 0.2°C on average. This is probably because the thermal insulation on the building prevented the heat from releasing to the outdoor spaces. In this case, RH level between both rooms were almost the same for the whole measurement period. Indoor RH was reduced to as low as 53% during daytime and increased by up to 90% at night.

In Case 5, the nocturnal air temperature in the master bedroom of House 2 was reduced by up to 0.7°C when the whole house ventilation was applied (Figure 3b). However, it was found that the structural cooling effects did not result in reduction of daytime air temperatures. The daytime RH in both rooms is about 55-65%. In night-time, RH in the master bedroom of House 2 is about 8% higher than that of House 1. This is probably because the humid outdoor air entered the room by the whole house ventilation.

Meanwhile, unlike the previous Case 3, there is no significant reduction in the nocturnal air temperature in the master bedroom in Case 6, even when the attic ventilation was added to the previous case (Figure 3c). The reduction of nocturnal air temperature in the master bedroom in House 2 is almost the same as that in Case 5 (0.7°C). This implies that the air temperature reduction seen in Case 3 is not due to the effect of attic ventilation but due to outdoor weather condition. This indicates that the attic ventilation did not contribute in lowering the nocturnal air temperature in the master bedroom. This is probably because the cooling effects by ventilation through window was larger than that of the attic fan.

Overall, the air temperature reductions during daytime in Cases 4 to 6 (i.e. comfort ventilation strategy) are smaller than those of previous Cases 1 to 3 (i.e. structural cooling) as expected, mainly because the windows were opened during the daytime. Nevertheless, indoor RH in the master bedrooms maintained lower values ranging from 53-92% in Cases 4 to 6 instead in the case of comfort ventilation strategy.

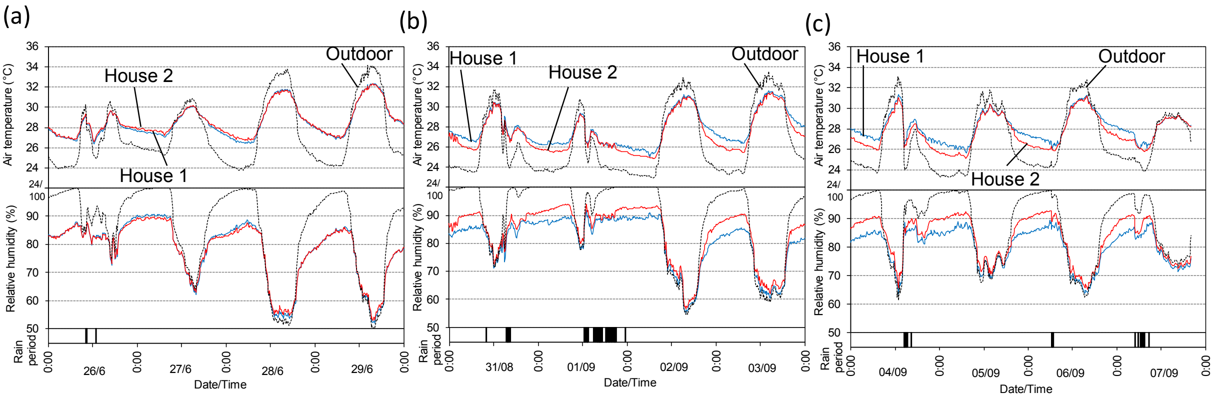

Figure 4. Temporal variations of air temperatures and RH in the master bedrooms of House 1 (H1_MB_S) and House 2 (H2_MB_S) (a) Case 4 (b) Case 5 (c) Case 6.

Thermal comfort evaluation in the master bedrooms

Figure 5 shows the daily average of indoor thermal environments in the master bedroom and the living hall under the two cooling strategies equipped with the proposed modifications (i.e. roof insulation, external wall insulation, external shading and whole house ventilation).

In the case of structural cooling (night ventilation), the air temperature in the master bedroom and the living hall tend to be lower than the corresponding outdoor temperature by up to 4.0-4.5°C during the daytime (Figure 5a). Meanwhile, in the night-time, the air temperature in both spaces are about 2°C higher than the corresponding outdoor temperature. In this case, the RH is always above 75% for the entire day.

In the case of comfort ventilation (full-day ventilation), the reduction of air temperature during daytime in the two spaces is smaller than those of the previous strategy (Figure 5b). The air temperature of the master bedroom and living hall are about 2°C and 3°C lower than the corresponding outdoor temperature. Nevertheless, it should be noted that the RH of the indoor spaces is lower than that of the previous strategy as expected, which is as low as 65% in the daytime. Meanwhile, the air temperature difference between indoor and outdoor during the night-time is almost the same as that of the former strategy, which is about 2°C higher than the corresponding outdoor temperature.

Operative temperature (OT) and SET* are used as indices to evaluate thermal comfort in the master bedroom and the living hall. As for the OT, the thermal comfort is evaluated based on adaptive comfort equation (ACE) developed for naturally ventilated buildings in hot-humid climates (Toe and Kubota, 2013). The 80% adaptive comfort upper limit from ACE is used for the evaluation. Meanwhile, a metabolic rate of 1.0 met and a clothing value of 0.4 clo are applied in the calculation of SET*.

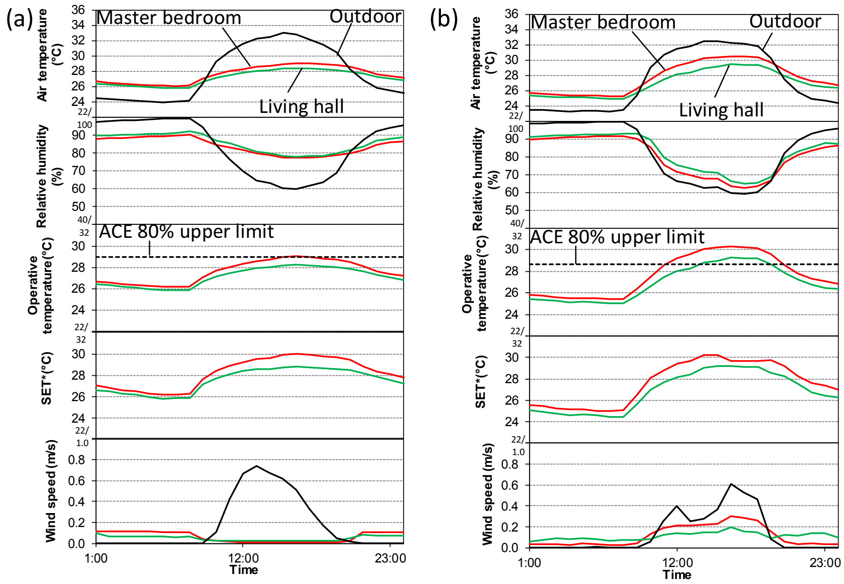

Figure 5. Indoor thermal environment of master bedroom of the proposed energy-saving strategy. (a) Structural cooling strategy and (b) comfort ventilation strategy.

As presented in Figure 5, the calculated OT of the master bedroom and the living hall in structural cooling record lower values (28.0 to 29.0°C) than those in comfort ventilation (29.0 to 30.0°C) during daytime. The OT of master bedroom and living hall in structural cooling generally fall within the limits, while those in comfort ventilation exceed the limit over 30% of the measurement period. Nevertheless, when SET* is used for the evaluation, those in the two spaces in the two cooling strategies show almost the same values during daytime (approximately 30.0°C and 30.3°C SET*). This indicates that if the effect of sweat evaporation is taken into account by using SET*, the resulting thermal comfort levels in the two cooling strategies are considered almost equal.

On the other hand, it can be said that the relatively lower RH in comfort ventilation is more tolerable than that in structural cooling since constantly high humidity condition (>70%) would cause mold growth (Johansson et al, 2012) and health related problems (Sterling et al, 1985). Hence, it can be concluded that the cooling strategy of comfort ventilation is probably preferable than that by the structural cooling for the hot-humid climate of Malaysia.

Conclusions

- The application of proposed modifications, i.e. roof insulation, external wall insulation, external shading and whole house ventilation successfully reduced indoor air temperatures by about 0.8°C during the day and night under the structural cooling strategy. Meanwhile, in the comfort ventilation strategy, the temperature reduction could only be seen during the night-time where the resultant air temperature reduction is about 0.7°C. Nevertheless, the whole house ventilation was not able to reduce the nocturnal indoor air temperatures as low as outdoor in both cooling strategies.
- It was found that the application of attic fan at night did not contribute in lowering nocturnal air temperature in the master bedroom. This probably because the cooling effects provided by the attic fan is smaller than that of ventilation through the windows.

- The resultant indoor thermal comfort of two different cooling strategies, i.e., structural cooling and comfort ventilation was evaluated by using OT and SET*. Although the OT in the master bedroom and living hall in structural cooling showed lower values than those of comfort ventilation, the SET* of these spaces in both cooling strategies was almost the same during the daytime (approximately 30.0°C and 30.3°C SET*). Considering not only indoor thermal comfort but also indoor air quality, the comfort ventilation (full-day ventilation) strategy was found to be preferable for the hot-humid climate of Malaysia.

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Multi-objective window optimization of school buildings for thermal and daylight performance in the cold climate of China

Anxiao Zhang[1], Qiong Huang[1], Yanchen Sun[1] and Qi Zhang[1]

[1] School of Architecture, Tianjin University, Tianjin, China

Abstract: The objective of this study is to provide a methodology for optimizing the window design parameters of school buildings with respect to the triple objective of energy use, summer thermal comfort and annual daylight conditions. The optimized variables are window-to-wall area ratio (WWR) and window type characterized by visual and thermal characteristics. The adaptive thermal comfort model of ASHRAE 55-2010 was used to evaluate summer thermal conditions since most schools in the cold climate of China are naturally ventilated in summer. The sum of energy demand for heating and lighting (EDHL) was used to assess energy use. The Useful Daylight Illuminance (UDI_{avg}, between 100 and 2000 lx) was adopted in this research for daylight evaluation purpose. Energy use and thermal comfort were calculated using the software EnergyPlus, and the UDI_{avg} was computed using DAYSIM. A multi-objective optimization based on genetic algorithm was performed in order to balance the antagonistic effects of the window variables on different objectives. Moreover, a definition of the “overall best” solution for further screening was proposed. This method offers the advantage of quickly providing the optimal solutions to the problem at early design stages, providing guidelines for designers in making decisions.

Keywords: School building, window design, multi-objective optimization, thermal performance, visual comfort

Introduction

Environmental comfort and energy efficiency are important issues in school building design since schools accommodate children for long periods of time. A discomfort indoor environment will negatively affect the health and performance of students and teachers (Corgnati et al., 2007). In the cold climate zone of China, the coldest mean monthly temperatures are between -10°C and 0°C, while the average temperatures in July range between 18°C and 28°C (GB51078-93, 1993). Such continental climate presents a big challenge to both architecture design and human activities from the view of an entire year: during winter, huge energy consumption is required to maintain constant indoor temperature of schools, while in summer most school buildings are free-running buildings without cooling system, leading to serious heat stress. Furthermore, a high level of daylight condition in classrooms is generally required to meet students' reading and writing demand.

Windows in school buildings characterize both thermal performance and visual comfort patterns. The size and physical properties of the window determine the availability of solar radiation entering building, which directly influences the energy demand of buildings or indoor thermal comfort through heat transfer process. On the other hand, the visible part of solar irradiation, namely daylight, affects the illuminance level of classrooms and changes lighting schedule, and thus indirectly influences lighting demand. Furthermore, it becomes even more complicated for buildings in the cold climate of China, where in hot summer solar radiation needs to be blocked outside the buildings, while in winter it is more inclined to absorb heat from solar radiation. For example, apparent window sizing contradictions occur when maximizing thermal comfort in summer but minimizing heating demand in winter.

In this paper, a method for optimizing the window of school buildings based on thermal performance and taking into account daylight was proposed. Three objectives, namely the sum of energy demand for heating and lighting (EDHL), summer thermal comfort and visual comfort, were optimized in the process. Window-to-wall area ratio (WWR) and window type were chosen as the design variables. The Pareto approach was applied to find the equally optimal solutions for the problem. The results will be used to improve facades design for school buildings in the cold climate of China.

Optimization methodology

In this research, the 3D graphic software Rhinoceros and its plug-in Grasshopper were applied to control the geometric parameters. The plug-ins Ladybug and Honeybee were used to add physical properties of building envelopes and connect to the energy simulation software EnergyPlus, and also the daylight simulation program Radiance. To evaluate energy consumption, annual EDHL was calculated as a main objective. Moreover, since most school buildings are naturally ventilated in summer in the cold climate of China, the adaptive thermal comfort model of ASHRAE 55-2010 was used in this study. The standard is based on the database compiled from several countries worldwide and has been proven more reliable than the standard Predicted Mean Vote (PMV) index in free-running buildings (De Dear et al., 1998). The summer thermal discomfort hours was then calculated. For visual comfort, the dynamic daylight metric Useful Daylight Illuminance (UDI) (Nabil et al., 2006), namely annual occurrence of illuminance at a given point that falls within a given range was applied. To describe classroom space, the average Useful Daylight Illuminance (UDI_{avg}) was calculated averaging the values of all the measurement points in the classroom. The threshold of UDI_{avg} was set at 100 lx and 2000 lx as a proxy indicator for both sufficiency and glare.

Furthermore, Octopus, an evolutionary multi-objective optimization component, was applied to perform the optimization. The Octopus is based on SPEA-2, an improved multi-objective evolutionary algorithm, which has shown to have advantages over NSGA II in multi-dimensional space (Zitzler et al., 2001). In this study, design variables are treated as genes and objectives as fitness values. In the multi-objective optimization, the Pareto approach was used, which provides a trade-off method among the objectives energy demand, thermal comfort and visual comfort. The Pareto front is mathematically defined as follows: Consider a system with function $f:\mathbb{R}^n \rightarrow \mathbb{R}^m$, where *X* is a compact set of feasible decisions in the metric space $\mathbb{R}^n$, and *Y* is the feasible set of criterion vectors in $\mathbb{R}^m$, such that $Y=\left\{y\in\mathbb{R}^m : y=f(x), x\in X\right\}$. We assume that a point $y''\in\mathbb{R}^m$ is preferred to another point $y'\in\mathbb{R}^m$, written as $y''\succ y'$ and called y'' dominates y'. Thus the Pareto optimal is $P(Y)=\left\{y'\in Y:\left\{y''\in Y: y''\succ y', y''\neq y'\right\}=\varnothing\right\}$. Pareto's simple idea of optimality can be verbally described as follows: "A solution is Pareto-optimal if it is dominated by no other feasible solutions, which means that there isn't any other solution, that is superior at least in case of one objective function value, and equal or superior with respect to the other objective functions values'' (Pareto, 1964). None of the Pareto solutions are better than the other, with respect to all of the objective functions. For a problem with multiple objectives, a set of Pareto-optimal solutions are obtained rather than a unique optimal solution, providing multiple choices for architects and policy makers. After a finite number of iterations in Octopus, non-dominated solutions, namely best trade-offs between those objectives, are produced and visualized.

Reference model

The reference model consists of a classroom of 10.0 m x 8.0 m with a height of 3.80 m, situated in the city of Tianjin in the cold climate of China. Four main orientations, namely south, west, north and east, are considered (Figure 1). It is assumed that the room is located on the third floor of a 5-storey building. The thermal transmittance from ceiling, floor and the partition walls that separate one classroom from other classrooms are set to adiabatic. The external wall is defined as a 0.30 m thick concrete-brick structure insulated with 50 mm board, with a U-value of 0.46 W/m^{2}K.

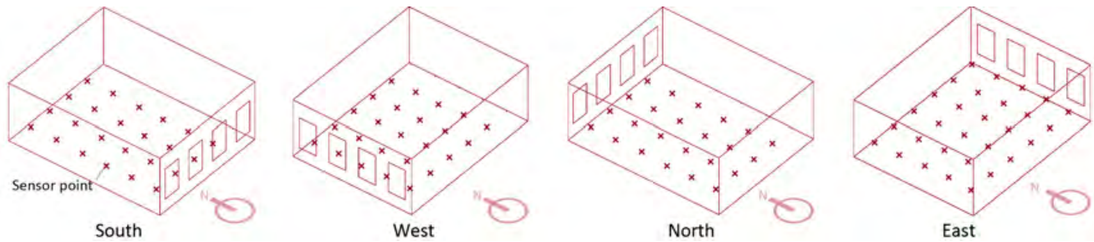

Figure 1 Three simulated classroom models. Lighting zone sensor points are placed based on a grid resolution of 2.0 m x 2.0 m at 0.8 m from the floor plane.

The school building is open from 8:00 AM to 5:00 PM during workdays. Typical Chinese school holidays accounting for 95 days annually are considered, which include holidays during the hot summer days and cold winter period. The lighting schedules for energy calculation are the results from daylight simulation by DAYSIM. In addition, the target illuminance value was assumed to be 300 lx for the classroom. A dimmed lighting system with an occupancy sensor is assumed. The photocell dims the activated lighting until the total work plane illuminance (daylight and electric light) reaches the minimum illuminance threshold. The Radiance calculation parameters are as follows: 6 ambient bounces, 1500 ambient divisions, 100 ambient sampling, an ambient resolution of 300, an ambient accuracy of 0.1, a limit reflection of 6, a direct threshold of 0, and a direct sampling of 0. The ideal loads air system is selected as the HVAC system in EnergyPlus, which is most suitable at the early-design stage considering calculation time cost. The heating set point is set at 18°C for classrooms. Internal gains (people, lighting density, etc.) comply with the requirements of local norms.

Design variables and objectives

The influence of window size is investigated with different window types for four main orientations (south, west, north, and east). The window size is estimated as WWR from 0% to 95%, with four glazing materials included in the window types, namely single clear glass, double clear glass, double low-e glass and triple low-e glass. More specifically, the details of the glazing materials are shown in Table 1.

Table 1 Characteristics of different window types

Type	Description	U-value (W/m^2K)	Solar heat gain coefficient	Visible transmittance
1	[Sgl: Clr 6 mm]	5.78	0.82	0.88
2	[Dbl: Clr 6mm/13mm Air/6mm]	2.67	0.70	0.78
3	[Dbl_LoE (e2=0.1): Clr 6mm/13mm Arg/6mm]	1.49	0.57	0.75
4	[Trp_LoE (e2=0.1): Clr 6mm/6mm Arg/6mm/6mm Arg/6mm]	0.78	0.47	0.66

Since Octopus can only solve minimization problems, the values of UDI_{avg} (100-2000 lx) need to be multiplied by -1. Similarly, summer comfort was evaluated using the percentage of discomfort hours. For energy evaluation, EDHL was applied. It is calculated as the annual energy consumption per unit of floor area (kWh/m^2) of the model. The objective is to minimize EDHL and maximize summer thermal comfort time and UDI_{avg} (100-2000 lx). The parameters of optimization algorithm are set as follows: elitism of 0.500, mutation probability of 0.010, mutation rate of 0.900, population size of 50 and maximum generation of 30.

Optimization results

The optimization was run for four times for different orientations with the above parameters. Each run took approximately 30 h on a computer with 4-core 2.70 GHz processor and 4G RAM. Figure 2 shows all the Pareto front solutions for the south-oriented and north-oriented classroom models in the objective-function space. These non-dominated solutions have one object-function out of the three that is lower than other solutions, being equally optimal.

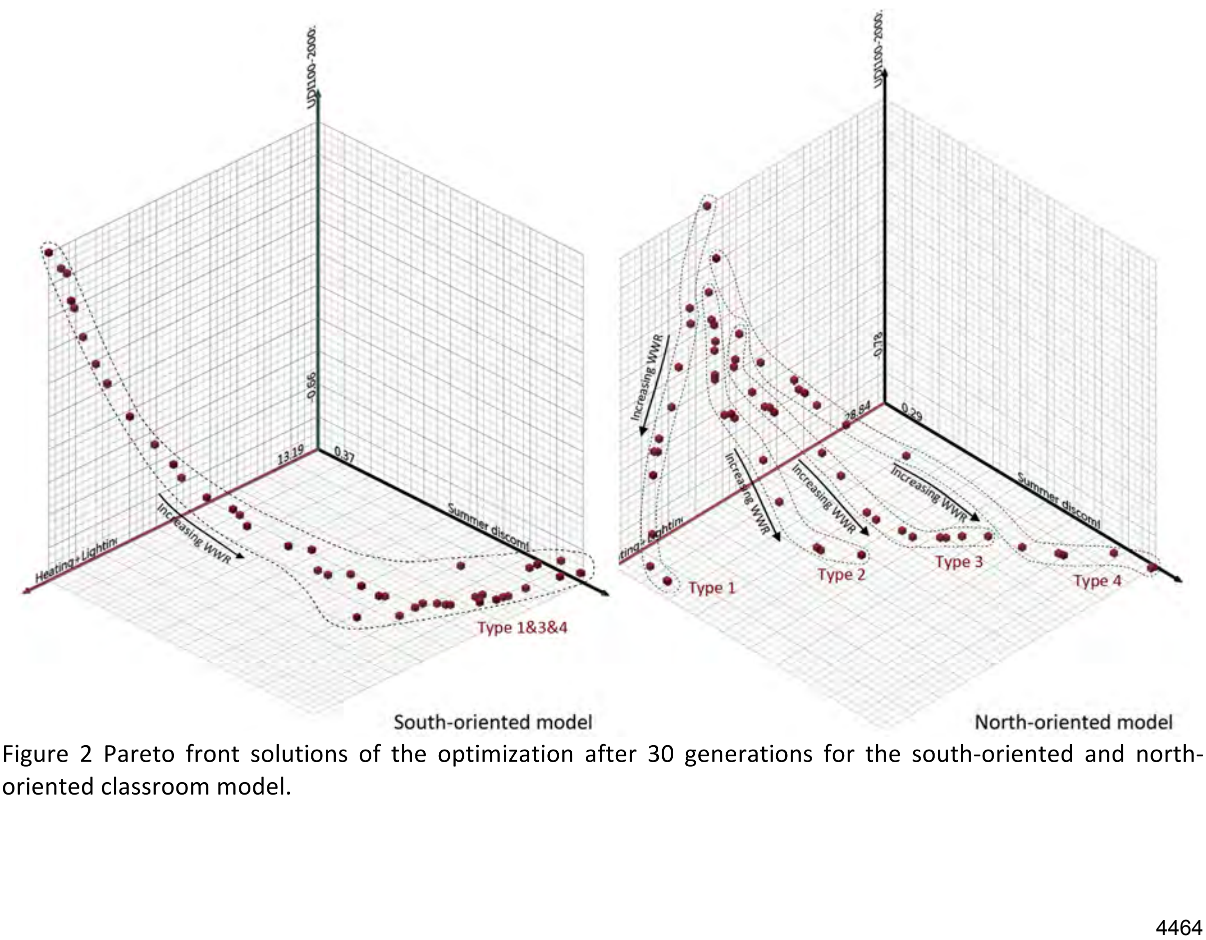

Figure 2 Pareto front solutions of the optimization after 30 generations for the south-oriented and north-oriented classroom model.

As can be seen, both of the Pareto solutions run from the upper left corner to the lower right corner. However, the Pareto solutions of the south-oriented model gather together into one line, while the solutions of the north-oriented model are grouped into four lines. Each line corresponds to a window type, and each point of the line corresponds to a WWR. Actually, the west-oriented and east-oriented classroom models exhibit similar grouping phenomenon (which is not shown here due to length limits). This indicates that window type has less impact on south-oriented classroom than the other three models, particularly for large WWRs. For better analysis of the non-dominated solutions, they were summarized in terms of their design characteristics and performances.

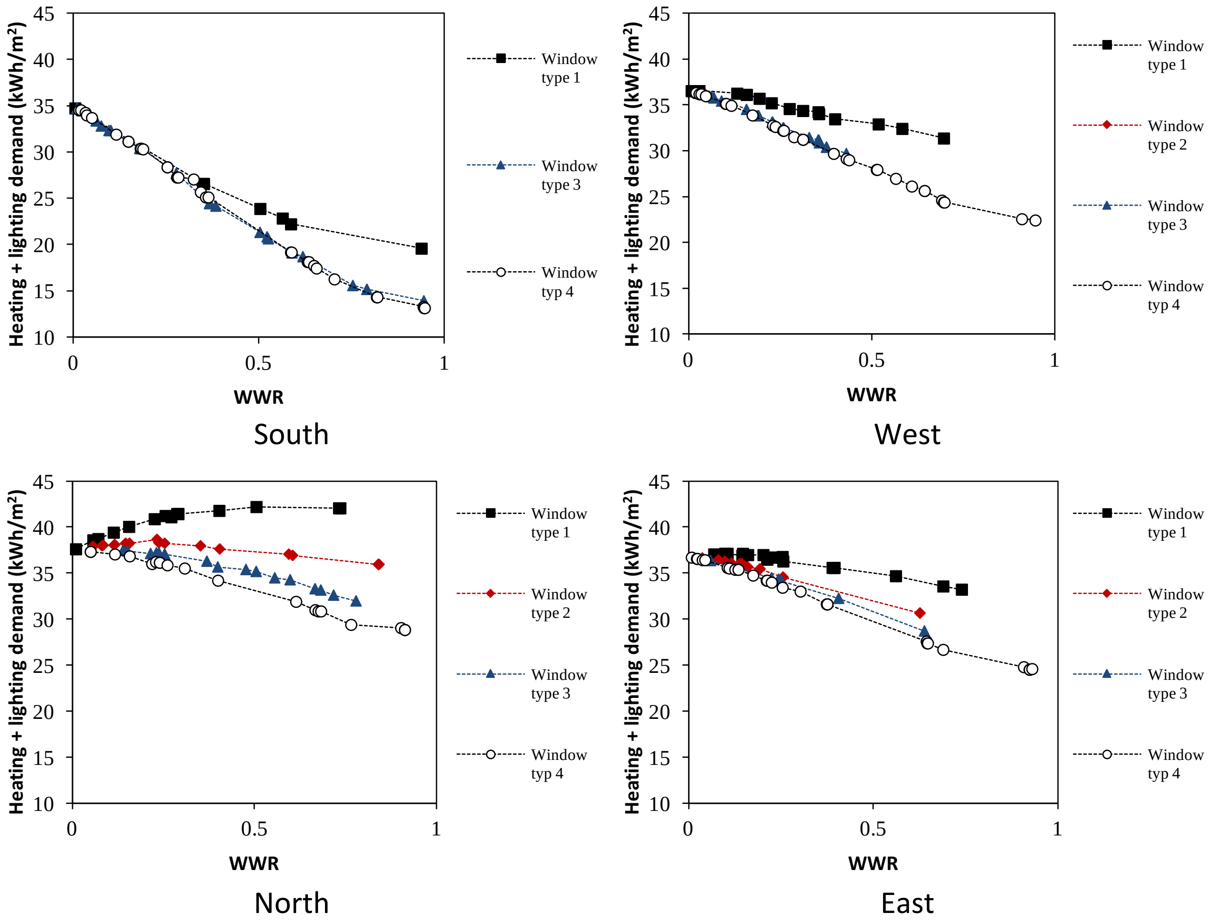

Figure 3 The energy performance for the Pareto solutions of four differently-oriented classroom models.

Figure 3 shows the energy performance for the Pareto solutions of four differently-oriented classroom models. It can be observed that almost all window types have a wide range of WWRs except window type 2, which is never optimal for the south orientation and only appears once for the west orientation. The EDHL decreases with the rise of WWR in most cases. The reason is that the increase of WWR results in more radiant heat and daylight penetrating into classroom, leading to the reduction of both heating and lighting demand. Furthermore, window type 4 shows maximum energy reduction for all the orientations when WWR increases, of which the U-value is the lowest ($0.78W/m^2K$), preventing heat loss to the greatest extent. On the other hand, window type 1 shows the least reduction, and there is even a slight increase in the north-oriented model as WWR increases. In this case when the U-value of window is high ($5.78W/m^2K$), the heat dispassion variation of the room due to the increase of window size is relatively larger than the sum of increased radiant heat and varied lighting energy. It is particularly obvious for the north orientation where there isn't any direct solar radiation, thus leading to the increase of energy demand as WWR increases. In addition, the energy demand shows the greatest reduction for the south-oriented room due to the large amounts of solar radiation. In high WWRs, south-facing room can reach a value of 13.3kWh/m^2, while for the other models the lowest energy demands are around 25kWh/m^2.

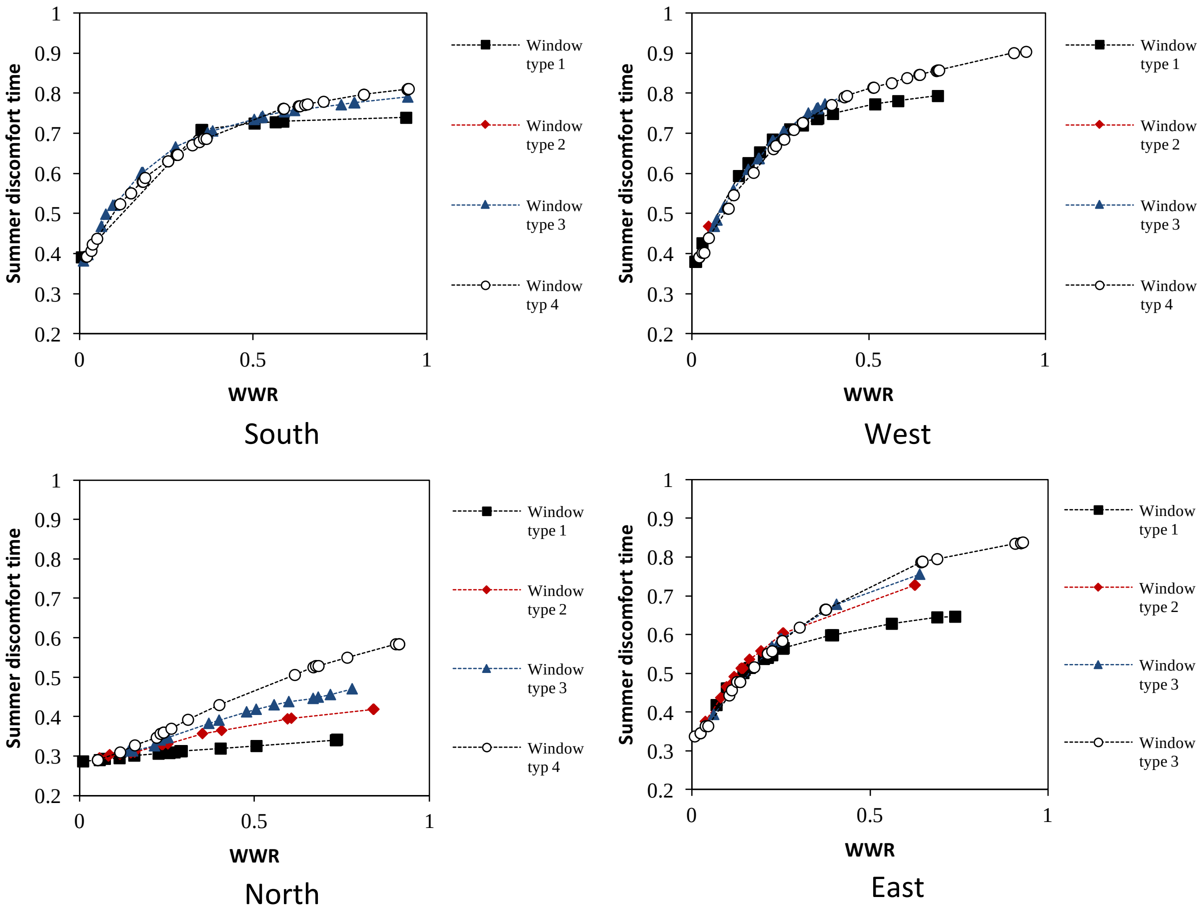

Figure 4 The summer discomfort time for the Pareto solutions of four different oriented classroom models.

The Pareto solutions for four differently-oriented classrooms were then summarized in terms of summer discomfort time, as shown in Figure 4. The discomfort time increases for all orientations as WWR increases due to the increased radiant heat entering the room. For a given WWR, window types with high U-values (e.g. type 1) lead to low summer discomfort time, particularly for large WWR models. In this case, the types with low U-value are not optimal for indoor thermal comfort since they prevent heat from going out and lead to overheating. Moreover, it can be seen that north-oriented room exhibits relatively lower summer discomfort time than other orientations because of no direct solar radiation.

Considering visual comfort, models of all the orientations show similar situations (Figure 5). UDI_{avg} (100-2000 lx) increases rapidly when WWR rises until approximately 50% when the UDI UDI_{avg} (100-2000 lx) remains at a stable level afterwards. A closer look at the four orientations when the WWR is large, the north-oriented model has maximum UDI_{avg} (100-2000 lx) (around 80%), while the south-oriented model has the lowest values (around

60%). The reason is that large WWR leads to excessive daylight penetrating into the south-oriented room and results in illuminance at some senor points above 2000 lx. Additionally, since the difference of visual transmittance of windows are smaller (maximum 0.22), the UDI_{avg} (100-2000 lx) exhibits similar patterns for all window types.

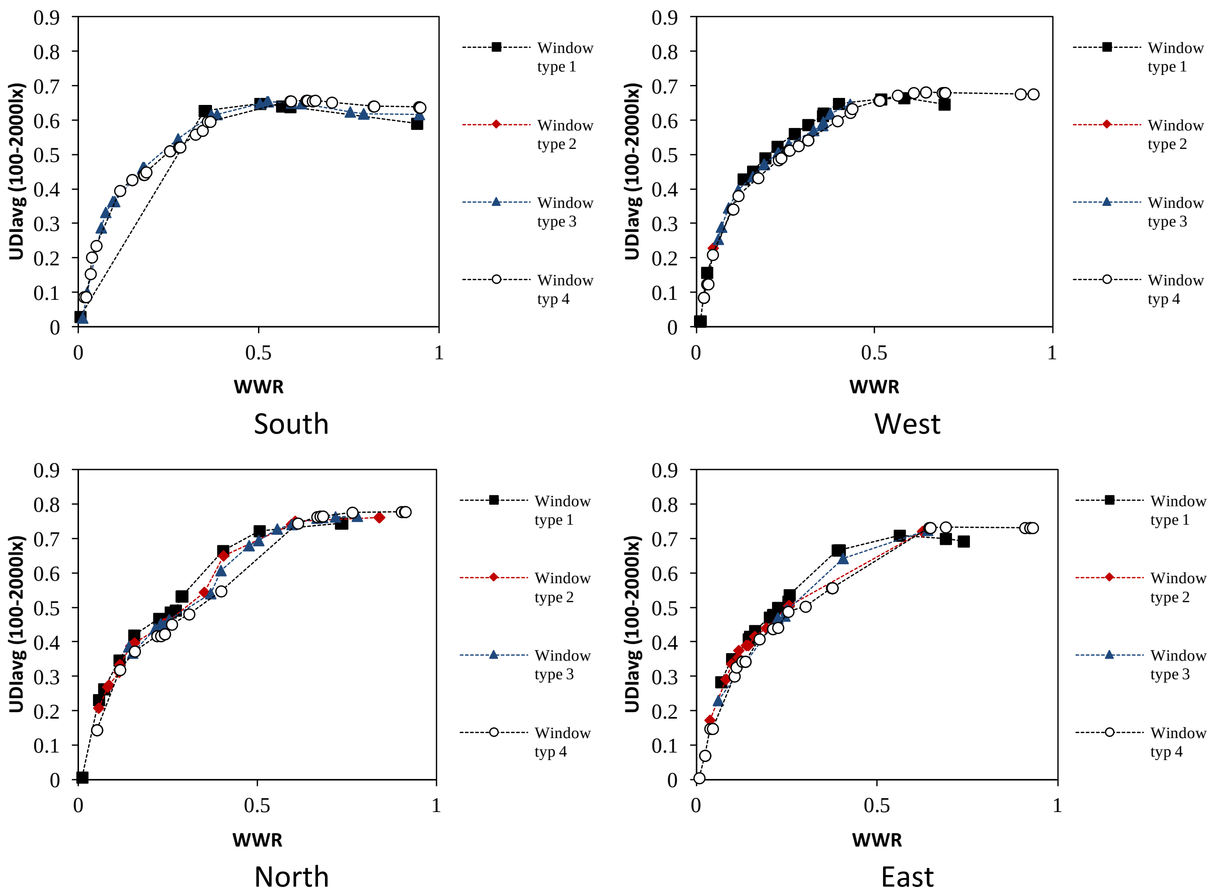

Figure 5 The UDI_{avg} (100-2000 lx) for the Pareto solutions of four different oriented classroom models.

Architects can choose any solution from the above Pareto front solutions. However, some extreme solutions might perform the best in some aspects irrespective of the other two performances. Thus a definition of the “overall best” solution is presented here for the reference of designers. It is the design nearest to the origin in the figure with the Pareto front which is calculated as follows (Eq. (1)).

$$OA_{best} = Min\left(\sqrt{\left(\left(\frac{(EDHL_i - EDHL_{min})}{EDHL_{min}}\right)^2 + \left(\frac{(STD_i - STD_{max})}{STD_{min}}\right)^2 + \left(\frac{(UDI_i - UDI_{min})}{UDI_{min}}\right)^2\right)}\right) \quad (1)$$

Where EDHL = heating + lighting energy demand, STD = summer thermal discomfort time, UDI = UDI_{avg} (100-2000 lx), I = result of iteration, min = minimum value in the set, max = maximum value in the set.

The final four chosen overall best solutions for each orientation are shown in Table 2. It can be observed that different oriented classrooms have different window “adaptation” methods to balance the three objectives. South-facing room has the highest WWR (74%) with window type 3, while north-facing room has relatively lower WWR (40%) with type 2. Moreover, both west-oriented and east-oriented rooms use small windows (10% and 11% of WWR respectively) with the highest U values.

Table 2 Summary of four overall best solutions for different models of orientation

Orientation	WWR	Window type	Energy demand (kWh/m^2)	Summer discomfort time	UDI_{avg} (100-2000 lx)
South	74%	3	15.6	77%	62%
West	10%	4	35.2	51%	34%
North	40%	2	37.6	37%	65%
East	11%	4	35.5	46%	33%

Finally, it is worth noting that decision-maker can choose site-specific solutions in terms of the relative importance of individual objectives on site. For example, allocating a weight to an objective-function or setting some constraints by eliminating some solutions according to on-site situation can help make better use of the Pareto solutions.

Conclusion

This paper proposes a method to simultaneously optimize three objectives, which are energy demand, thermal comfort, and visual comfort. The adaptive thermal comfort model and UDI_{avg} (100-2000 lx) were used in the evaluation of thermal comfort and visual comfort respectively. The design variables of the problem are window-to-wall area ratio, and the window type. The set of potential solutions was computed using Ladybug and Honeybee coupled with EnergyPlus and DAYSIM. Lastly, the Pareto approach was applied using Octopus to optimize the three conflicting objectives.

The results show that the increase of WWR will decrease energy demand, while increase both summer discomfort time and UDI_{avg} (100-2000 lx) in most cases. South-oriented room is more inclined to have lower energy demand whereas north-facing room has generally less summer thermal discomfort hours. Furthermore, some window types are rarely optimal in specific-oriented rooms, e.g., Type 2 is not suggested to be used in south-facing and west-facing rooms. High U value of window is beneficial to the decrease of energy demand but has negative effect on summer thermal comfort particularly for large WWRs. In addition, window types exhibit similar effect on the UDI_{avg} (100-2000 lx). Finally, a definition of the “overall best” solution to balance the multiple objectives is proposed for the reference of designers. This multi-objective optimization method offers the advantage of quickly giving the optimal solutions to the problem, providing guidelines for architects. The approach can also be used for other optimization problems in a design procedure.

Acknowledgements

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Place Making and Well-being

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Place Making and Wellbeing: The Story of Forbidden Space

Sahera Bleibleh

United Arab Emirates University , Al-Ain, The United Arab Emirates

Abstract: People mostly appropriate, and reappropriate, everyday spatial practices in time of peace as well as in time of conflict. In so doing, the "practice of everyday life" conveys much about place making and wellbeing. In wartime, home becomes a forbidden space where life is considered a collateral damage; therefore, people lose their memories and a life they once had. Place making fundamentally creates rightful environment that supports undisturbed everyday practice and equally empowers place attachment. This paper explores the ways in which people experience space disorder in warfare time when they were/are forced to evacuate and seek shelter in a temporary place not knowing when, or if they will ever be able to return home. It investigates the consequences of sudden blowing up home and its significant attributes. Following an ethnographic approach in the old town of Nablus and Jenin Refugee camp between 2010-2014, this paper discusses the spatial and behavioral disorder of war and displacement. It focuses on the impact of Israeli occupation military continuous assaults that transform the entire space of Palestinian life into a theater of war. Homes are no longer secured. The very intimate space and social life is dehumanized as the Israelis turned the Palestinian urban fabric into landscape of and for war. It also disturbed the essence of the daily life and created a "forbidden space" that contradicts the fundamental meaning of home. Such military strategy in the domestic space is meant to annihilate the everyday tactic of resistance under the occupation, which creates further struggle over the meaning of space/place thus questions the essence of place making, well being and trauma. In conclusion, peoples' narrative of place making helps us reimagine the spatial politics of emancipation in the aftermath of each attack. The resilience of space of enjoyment that arises against spaces of annihilation is a positive appropriation and transformation of forbidden space into place making. At this point, the assembling of everyday pieces into a collective space resonates with insurgent practices of temporary pleasure and create a space of joy and dominance.

Keywords: Place making, forbidden space, everyday life, wellbeing, Palestine.

Introduction

This paper attempts to discuss the responsiveness of the urban fabric of two compacted sites in Palestine to the social and socio-economic needs while continuously experiencing political struggle under the Israeli occupation. Drawing on ethnographic research among Palestinians whose homes were destroyed during the 2002 *Edjteyah*, in the old town of Nablus and later in Jenin Refugee camp. I explore the impact of Israel's *invisible* warfare upon the physical and social meaning of place, community, identity and "building with change." Interviews, focus groups and participant observations were conducted in Nablus from 2009 to 2011, and from 2012 to 2014 in Jenin refugee camp. These interviews were carried out with residents, refugees and institutional representatives. The inhabitants' experiences after their homes were invaded and bombed, and the ways in which they took care of themselves and worked to repair the damage, tell a story of resilience and agency that is critical to understanding the breadth of the "everydayness." Moreover, the inhabitants' interactions with the local institutions and established local committees that were involved in the repair process during the post-reconstruction presented, and presents, a significant example of people collective commitment to rebuild their homes based on the foundation of its historical legacy and their hopes for future that preserves their culture and identity. This effort not only reflects colonial power but also the humanitarian aid control over people's sovereignty.

According to Weizman (2007) in *Hollow Land,* during 2002 Israeli invasion "soldiers avoided using the streets, roads, alleys, and courtyards that define the logic of movement through the city, as well as the external doors, internal stairwells, and windows that constitute the order of buildings; rather, they were punching holes through party walls, ceilings, and floors, and moving across them through 100-metre-long pathways of domestic interior hollowed out of dense and contiguous city fabric." This maneuvering makes everyday life activities invisible where outside movement becomes the inside and people have no control on their domestic space anymore. The political dynamics create flexible medium where the inside is borderless against the external imposed control. The political space created by Israel's colonial occupation from the deep profound spaces of the West Bank (and Gaza) to their militarized airspace, Weizman unravels Israel's mechanisms of control and its transformation of the Palestinian land into a theoretically constructed artifice, in which natural and built features function as weapons and shells with which the conflict is waged. In exploring Israel's methods to transform the landscape itself into a tool of total domination and control, *Hollow Land* lays bare the political system at the heart of this complex and terrifying project of late-modern colonial occupation. Warfare delineates both internal and external spaces where public and private become a space of tactics and control where typologies no longer represent the real function of spaces in ways where the meaning of space is distracted. To reflect on such policy one of the interviewees mentioned that women, while inside, remained dressed up and wearing their veils in case of any unpredicted invasion of their living space, following the Israeli newly introduced military strategy of "walking through walls". These images intersect with de Certeau's argument on the mixed use of space between names and practices, "[t]he presence and circulation of a representation … tells us nothing about what it is for its users. We must first analyze its manipulation by users who are not its makers. Only then can we gauge the difference or similarity between the production of the image and the secondary production hidden in the process of its utilization." This notion might also be debatable when the *utilized* space is threatened by external forces that contribute to manipulate its perception.

The "walking through walls" strategy represents the logic of reorganization of the built urban syntax because it manipulates or ignores the existing pattern of streets or movement and replaces it with another more damaging circulation system. By liquidating urban structure, it becomes easier to control on-site planning where paths are determined in response to opportunities. It is, Eyal Weizman (2007) states, meant not just to occupy but also to reorganize the space of colonized cities, so that modern warfare with its high-tech weapons and surveillance systems can work to the colonizer's best advantage. Describing it as "design by destruction," Weizman asserts, "contemporary urban warfare plays itself out within a constructed, real or imaginary architecture, and through the destruction, construction, reorganization and subversion of space" (Misselwitz & Weizman, 2003, pp. 272-275). In this sense, military strategic thinking has been developed to overcome the complexity of the city; thus, war has evolved from being "in the city but for the city, by the city. The city has become no longer the locus, but the apparatus of warfare" (Misselwitz & Weizman, 2003, p. 279; Weizman, 2006, 2007). This unexpected penetration of war into the private domain of the home was also carried out in Iraq by the U.S. military. The strategy, based on joint military training between the United States and the Israeli armies, has become the most profound form of humiliation and trauma for the invaded communities (Misselwitz & Weizman, 2003).

The newly introduced Israeli military technique of “walking through walls” not only affected the significance of this hierarchical relation, but also the household members were left in fear and insecurity within their own “nuclear” space, and thus the “nuclear” space is no longer as private nor safe anymore; rather, it is a “forbidden space.” Space is forbidden for the participants to live freely, and allows for the Israelis to brutally invade their privacy and *normal* life. The bombing and the “walking through walls” military technique had turned their homes, possessions, and lives inside out. Several participants, like Um Raed, Um Jehad, and Um Jamal and her daughters, needed to remain dressed up with their head scarfs in anticipation of any possible future attack to their homes. The compacted urban fabric allowed for some flexibility to move between homes in time of the attack, which in some cases enabled the neighborhood to act as one family. As Um Jehad stated, “During the *Edjteyah* time, we were always dressed up and ready to leave … I was mostly concerned about my eighteen year old daughter. I didn’t know what to do except protect her with my body.” In similar context Um Jamal’s daughter said, “We slept wearing our *jilbabs* and *esharbs* [long dress and head scarfs]” and Um Raed stated with distress, “*Wallah ya binti* [With God’s name my daughter], we had tough days. Our inner space and privacy had been invaded, *enkashaf halna* [literally, “our situation had been exposed” to indicate an invasion of privacy]. ”

Furthermore the Israelis’ gave no consideration to the possible health impacts destroying walls that released toxic dust and other hazardous materials. Although Abu Ridha continues to live in the basement to be close to his assassinated son’s memories, he affirmed,

> “Since the day of the *Edjteyah* till now my livelihood was cut off, and I got sick, I have asthma because of the weapons and the tear gas used by the Israelis, later I had a stroke in the brain, a heart attack and nerves break down… [Looking around the basement, it is a small place with little furniture, the smell of mold, peeling paint, and a small window below the ceiling. It was dark and the light was turned on despite the daylight outside, and therefore the door was kept open].”

While the compacted urban fabric supports everyday urbanism in both sites, the political hybridization affects its vernacular resilience. When the “inside” is redefined to mean “invisible”, and “outside” is redefined to mean “visible”, patterns of movements are not governed by the order of space; rather the movement itself produces space around it. This metaphor introduces another perspective on understanding patterns of movement within the urban complexity strikingly leads scenarios to defeat the city’s customary space. The “outside” space metaphorically becomes Bhabha’s “third space” or de Certeau’s “site of resistance” and both represent the resilience of not only survival of people but also history and culture. The “inverse geometry” that was conceived to turn the city “inside out”, shuffling its private and public spaces, would now transform and re-conceptualize the sense of security and the meaning of space under pressured situations.

Lefebvre’s description of space as being a social product varies between the perceived space, the conceived space, and the lived space. All these categories make “as if the sum of the individual parts do not equal the whole”. The argument that people have influence over shaping their spaces, and that they are in turn shaped by them is valid; however, there are external forces that also contribute to shaping both spaces and people. Such forces are sometimes out of control, mainly when they are related to politics and conflict where their influence is either hard to ignore or predict. Though danger and fear are not physically represented, their implications are reflected on the physical urban structure the same way they are reflected on people. Therefore, the indirect unforeseen danger becomes a force of hybridity that shapes spaces the same as direct forces do. This correlates with Lefebvre's argument of space as social product, and also a political product, and here it's worth reconsidering Lefebvre's concept "the right to the city". How we will reflect on this concept when a place is destroyed, yet gaining more meaning and stronger memory?

Methodology

Building on ethnographic research in the old town of Nablus between 2009-2012 and in Jenin Refugee Camp in 2013-2014, to collect stories of people whose homes were destroyed during the 2002 *Edjteyah*, this article explores how the Palestinians encountered, and encountering, the aftermath of the Israel's invisible warfare upon the physical and social meaning of place, community, identity and "production of illegitimate social space." Interviews, focus groups and participant observations were conducted in both sites. The interviews were carried out with residents, refugees and institutional representatives. The larger research focuses on the peoples' experiences after their homes were invaded and bombed, and the ways in which they took care of themselves and worked to repair the damage, tell a story of resilience and agency that is critical to understanding the breadth of the "everydayness" and human well being. Also, their interactions with the local institutions and established committees that were involved in the repair process during the post-reconstruction of the historical town of Nablus and Camp presented, and presents, a significant example of people collective commitment to rebuild their homes based on the foundation of its historical legacy and embraces their distinguished sense of place and connectedness.

Production of Illegitimate Social Space and Wellbeing

Besides the damage caused by the "walking through walls," several buildings were totally destroyed in the old town of Nablus, and a complete neighborhood (Hawashin) in Jenin Refugee Camp. The municipality of Nablus steered the reconstruction in the old town of Nablus, and the UNRWA took care of the camp. During the 2002 Israeli invasion *Edjteyah* neighbors joined each other for refuge. Therefore, the interior space has been divided to accommodate gender privacy for those who were forced to stay together. For example, in a basement of one family of seven households has to accommodate fifty persons during the invasion. The basement was divided with a blanket and a hole was excavated to provide a toilet to avoid any embarrassment for women who want to have some privacy. This experience offered the opportunity to understand the space layout in time of danger. Consequently, the distribution of the interior layout was considered for amendments in the reconstruction phase.

While confined inside, most households learned more about what they considered "vulnerable areas" in their homes thus reconsidered the distribution of the internal space and introduced spatial modifications. These changes varied according to the use of space and the households' particular experience, for example, entrances, either by material, location, size, or additional entrance; interior layout and exchange of room use to distance bedrooms from the outside; new building materials and construction technique rather than the traditional one; opening size and location; increasing roof parapets height; external facades alignment; and street widening. Although committees of the local communities were established to share responsibilities in reporting on damages and needs, in several cases, it was the municipality decision based on case-by-case evaluation. The committees in Nablus and Jenin were jointly formed of those whose houses were damaged. Although women representation was limited on the official level, none of them were included from those who experienced the "walking through walls." Um Alaa's narrative explains the situation, "Imagine you and your family are sitting in your living room, watching television and chatting together after the evening meal … suddenly, you hear a tremendous roar and the wall disappears. The room fills with dust and rubble, and the soldiers, one after the other either with masked or painted faces, show up through the wall. The children are screaming, panicking … not knowing what to do or where to go when submachines guns pointed everywhere. It is like a nightmare!" Um Jamal, who lives in the old town of Nablus, was content to convey her needs to her son who was following up on the reconstruction of their damaged home. She states, "My son, Allah yerdha 'leih [God bless him] decided we need an external stairs as a second entrance, so we use it in times of emergency. It was constructed against the Municipal law [limitations on making any changes in the historical site], but we need it. As you see, the old town is so compact and we need a way out in case something happened. My son was checking the progress of work during the construction time, his approval was taken for any changes, we [as women] were not allowed to interfere, but we were fine with the outcome." Although Um Jamal expressed satisfaction of the overall reconstruction work, she and her daughter, similar to the case of most women, were excluded from the rebuilding process.

Perhaps one of the most tragic memories for some of the women of the *Hawashin* neighborhood in Jenin Refugee Camp was the loss of their sons, in top of the loss of their homes. Women were compounding the loss of their beloved and their homes. This double loss for Um Mohammed resulted in her inability to remember her son properly since much of their lives together emerged within the space of their home, which has been damaged. She affirms, "I swear by God that I can't recall this period [when my home was destroyed]. I remember myself standing in front of my home and I was shocked. I couldn't go inside the home because of the strength of the trauma. It was great loss: the loss of my son, my home and the memories where I raised Muhammad."

Rula was one of the camp residents relocated to a new quarter after the reconstruction. The new site, however, left her feeling alienated both from the memories of her son and the lives they built as part of the neighborhood. According to her, the destruction of the *Hawashin*, her home, and her son left her feeling in a state of extreme estrangement.

> "I still feel a tremendous loss. I lost my house, my neighborhood, and my neighbors with whom I lived for more than 20 years, with whom I gave birth to my children and raised them. I lost all the memories of those who have perished. Because of that, I am incapable of coping or adjusting to this new place."

Manar expressed similar feelings of loss and estrangement as a result of her son's death and the destruction of the *Hawashin*. "Whenever I remember these events, I feel sick with emotional stress. Bad dreams attack me day and night. Yesterday, I got up from my nap shouting that I had lost Imad. I screamed his name loudly. No matter what happens, a mother never forgets. I shall never forget, never." Like Rula, the link between her son's death and the destruction of the neighborhood complicated the present experience of the camp. "Honestly, I no longer see the camp as something beautiful even though it is much prettier and the infrastructure is much better. Many of the youth were either killed or imprisoned [during the attack], like my sons. Memories of a house are linked with its owner and, nowadays, when I walk through the camp and see the houses without their owners, I feel bad. I lose my interest to continue walking in the camp."

Obviously, contribution of women in the reconstruction of their homes was limited, if not eliminated. Husbands, sons and brothers steered most of the committees to communicate and follow up on the reconstruction. The pain of loss women were suffering kept them isolated from any crucial contribution in the reconstruction. They, later, have to live the hostility of living in a" cold and empty place" of their precious memories that were lost twice. Surprisingly, their contribution during the *Edjteyah* contradicts with theirs after. While they demonstrate heroic stories of steadfastness and resistance by supporting and feeding those who were fighting the Israelis during the invasion, their presence was eliminated during the reconstruction.

Conclusion

This article presented the accounts of Palestinian women who survived the Israeli Edjteyah of the old town of Nablus and of Jenin Refugee Camp. These representations offer a critical insight into the way some women experienced the Israeli assault. It argued that the memories of these women illustrated the complex intersections of voice in which individuals and the collective are deeply intertwined. Thus Palestinian women recalled the violence of Edjteyah from viewpoints that combined their own perspective on events with those of others in both sites. In this sense, Palestinian women offered a collective memory of the attack in ways that not only highlighted their solidarity with others but also positioned themselves within a larger social body. Their perspective was a shared one in which individuals and community were deeply imbricated. Moreover, women's accounts underscored particular forms of agency rooted in their social location as women. Motivated by their deep concern and love for their children, Palestinian women took great risks and defied the Israeli assault in ways that can be described as heroic. There actions, however, did not conform to the ideological constructions of the Palestinian nation. Rather, their accounts suggest an understanding and experience of agency grounded in their own social perspective as women who aid and support a resistance that they're never quite a part of.

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Design to Thrive

Reinventing the Historic Townscape – a Guanshan Story

Yun-Shang Chiou[1], Yu-Hsi Hsieh[1] and Yu-Hsiang Huang[1]

[1] Department of Architecture, National Taiwan University of Science and Technology, Taipei, Taiwan, email: ychiou@mail.ntust.edu.tw

Abstract: Situated in the Huatung Valley in eastern Taiwan, Guanshan Township was established in 1915 by the Japanese colonial government to control aboriginal Taiwanese and to develop the valley's nature recourses. Grid-pattern streets, government institutions, public education system, agricultural and forest industries were carried on after WWII by the Taiwanese Government. It was not until 1980s when the eastern and western railways connected that Guanshan's population started to decline. Today, Guanshan is aging yet many old structures still stand. In the summer of 2016, a team led by the authors took initial steps to reinvent the townscape of Guanshan. The cultural corridor and the historic railway corridor were proposed to break the spatial pattern of homogeneity. With local residents' participation, three ill-managed sites in the corridors were transformed into highly popular public spaces with art installations. Several shopfronts were renovated. A series of events was hold in an old house to evaluate the feasibility of converting historic structures to public cultural facility. Precious lessons were learnt in the reshaping of public and private spaces of Guanshan.

Keywords: Guanshan, urban artefacts, direct experience, townscape, place making

Introduction

Covered by stone-filled land and lack of stable water supply, up till early 19th century, few human settlements can be found in the vast area over the 150 km strip of Huatung Valley. Occasionally, Bunun tribe in the Central Mountain and Amis tribe in the Coastal Mountain descended to the valley for hunting. This territory was not even on the map of Chin Empire. The first permanent settlements in Huatung valley were established in mid-19th century by Pinpu tribe. The Pinpu was displaced from the homeland in southern Taiwan due to territory expansion of Han-Chinese. Thanks to Pinpu's knowledge in rice farming, waterways were opened, land parcels were cleared, the food production was finally enough to sustain permanent population. Both Pinpu and Amis started to settle in the valley. By late 19th century, there are eight Pinpu settlements scatting across the valley, Guanshan (old name "Riran") was the southernmost of them. In 1895, Japan took over Taiwan from Chin, the Pinpu settlement of Riran was shown on the the 1902 and later maps (Fig. 1). In 1896 census of Riran, the population of Pinpu was 300 whereas that of Han-Chinese was 39 (Hsu, 2007).

Figure 1. 1902, 1924, 1944 Historic Guanshan (Riran) maps (Centre for GIS, Academic Sinica)

In 1915, the Japanese colonial government established Guanshan Township to control aboriginal Taiwanese and to develop the valley's vast nature recourses. On 1924 map (Fig. 1), the grid plan has replaced the original one-road settlement and guided the development of Guanshan in the following 90 years.

The grid plan of the Japanese Guanshan was centred on the east-west railway station – police station axis, signifying its role as the power of authority and the hub of transportation. Along the axis are the buildings for regional political- commercial activities. North of the central axis is the daily life axis evolved from the old Pinpu settlement. Public school, market, local shops, theatre, and Mazu (Sea Goddess) Temple all sit in this district. South of the central axis is the residential sector for government officials. The area was outside the original Pinpu settlement and mostly occupied by Japanese. On the north-south direction, supporting facility such as warehouses, railway dormitories were built along the railway whereas government and police officer's residences and supporting facilities were built along the front road of the police station (Fig. 2).

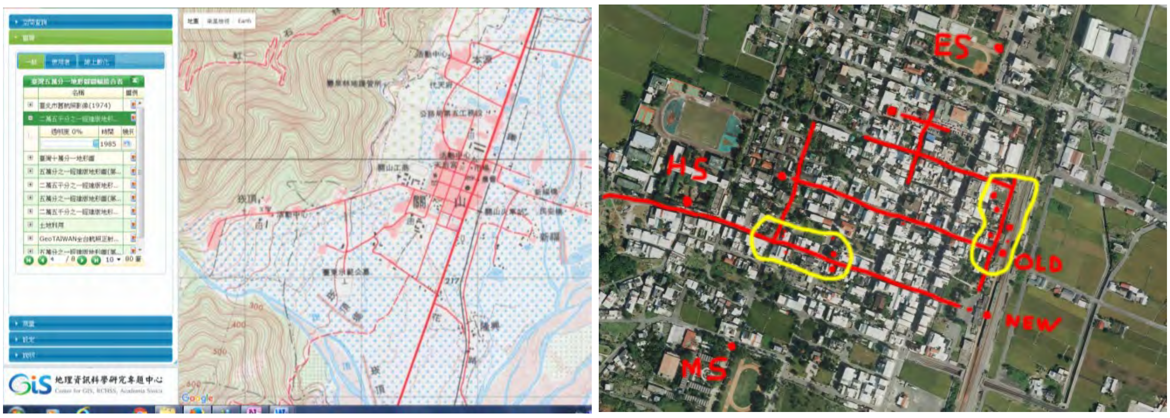

Figure 2. Guanshan 2009 Aerial Map (Centre for GIS, Academic Sinica) notation by the authors

The plots in the grids were divided into private lots. There was no room for public spaces. Different demographic groups lived in different sectors of the town and were highly segregated. A quick survey of the elders has found that most people only familiar with a small segment of the old town, they grew up together yet hardly sharing memories beyond their school life. It was a town of authority, a reflection of the mind-set of the colonial government. The life style of Guanshan continues long after Japanese left. While Guanshan is aging and losing young population to big cities since the connection of eastern and western railways in 1980s, segregated history of different demographic groups still left invisible barriers among town residents.

In the 2016 government commissioned project "Guanshan cluster of culture and creativity enterprises", the authors, who have been documenting the historic structures of Guanshan, led a team of NTUST students to reinvent the townscape of Guanshan according to modern values. The scope of work includes three public spaces and eight private shopfronts. Rossi's notion (1984) that the quality of urban artefact, like sound and smell, often can only be felt through "direct experience" is applied in many aspects - especially in the involvement of stake holders in the process of design creation. The project serves as an aspiration of the redevelopment of Guanshan in 21st century.

While the project itself is a great success with applauses from locals and publicities in news media, its limitation was also observed. Even if the town becomes people and business-friendly, local residents feel that without quality healthcare and education systems, it would still be difficult to attract young and senior families to settle down in Guanshan.

Design analysis – Guanshan in evolution

The scope of the project includes art installations in public spaces and renovation of shopfronts, exact locations were up to the design team. In approaching a cohesive philosophy in site selection and design intervention, the evolution of Guanshan townscape was first analysed.

Since established by the Japanese, the image of Guanshan is defined by two visual elements: the homogeneous street grids and the axis-based urban function districts. By choosing walking along or walking across streets of main axes, the sequences of urban artefacts that represent either similar or different urban functions will give very different tastes of and provide orientations to the grid-plan Guanshan (Fig. 3).

Figure 3. Street scenes of three functional district (official's residence, centre, Mazu temple)

The economy and population of Guanshan has faced continuous decline since 1980s. Out of the five functional axes previously described, only the regional political- commercial street axis and the "daily life" street axis still maintain their vitality. As a result, the image of grid-pattern now overtakes the image of axis-based urban function and gradually erases the sense of orientation of the historic Guanshan.

The change from an agricultural settlement to a political-commercial centre in 1915 also changes the pattern of interactions among the residents. In Taiwan's agricultural settlements, residents are bounded by their shared identity and it is quite common seeing clusters of people chatting in someone's front yard for pastime. Although surrounded by rice field with population around 3000, such scene was never observed in Guanshan. Privatization of properties and the invisible divisions among people of different demographic groups is also observed. It is likely a lingering influence from Japanese "class" specific policy that often seen in colonial ruling.

Guanshan's identity as an urban centre rather than a rural settlement indicates a need of public facilities for community bounding. It is interesting however, there was not such place in the official zoning of Guanshan during Japanese ruling. The only exception is the front court of Mazu temple in daily life street axis. It is not surprised because Guanshan was established to control local people at the first place.

Design strategy - Guanshan re-orientation

Rossi (1984) saw a city either as "a gigantic man-made object, a work of engineering and architecture" or "urban artefacts, which like the city itself are characterized by their own history and thus by their own form." Rossi describe the core presence of the urban artefact as "one is struck by the multiplicity of functions that a building of this type can contain over time and how these functions are entirely independent of the form. At the same time, it is precisely the form that impresses us; we live it and experience it, and in turn it structures the city." While Lynch (1960), point out the five elements that construct the image of a city, Rossi's emphasis on the importance of direct experience give a more intimate view on how the quality of a city is apprehended.

This project attempts to revitalize Guanshan townscape of grid plan and functional street axes and to create places that facilitate events to unite people. Rossi's notion of urban artefacts provides design guidelines to approach such objectives. The design solutions of new urban artefacts need to meet following criteria: 1. connecting past and present in visual context while its function can be free from historic reference, 2. maximizing stakeholders' direct experiences, especially "experience to share", of the quality of the urban artefacts.

Due to limitation of resources, the project team focuses only on "railway facility street" axis (the railway corridor) and old "residential sector for government official" street axis (the cultural corridor). The former was chosen because of its visibility to people in and out of Guanshan as the edge of a city, the latter was chosen because of its role as the corridor of education (district) and the connector (path) to the nearby village of Bunun tribe. The shopfronts were selected from a pool of volunteer business owners, based on the historic characteristics of the building and the contribution of the business to the vitality of daily life.

To expand the "direct experience" as shared memory, we intentionally invited different sectors of people to be involved in the project, including the initial discussions and the approval of design scheme in the town hall meeting, shopfront selection jury with local opinion leaders and the detailed design and construction with local artisan, carpenter, metal work, plumber, electrician and high school students and teachers.

Design implementation

a. The railway corridor

The old Guanshan railway station was built in 1936. For four decades, the railway station corridor has been the centre of town activities. Along the east-west main street facing the train station, there are shops, restaurant, hotels, and all kind of business. Along the north-south direction parallel to the railway, there are open water channel, linear garden, station chief's residence, dormitories for railway worker's families and the warehouses of farmer's association. The corridor carries the collective memory of Guanshan (Fig. 4).

Figure 4. Historic photos of the railway corridor (dormitory, old station, Jabin Hotel, vendor by the waterway)

The railway station corridor faces a steady downturn since late 1970s. . The connection of eastern and western railway drew people to cities. Local business started to decline. In 1980, a big fire burn down half a street block of the wooden structure facing the old station, a new station of concrete structure was erected 100 meter south and the old station was converted to warehouse. In coming years, the north-south water channel were covered and garden was removed to make motorway, the railway workers moved out and the dormitories fell into shambles. In 2015, most historic structures were gone; leaving only gravel ground and a few old trees from the past era. Government funded the restoration of the old station and station chief's residence in early 2000s. It brought back some memory but a sustainable business model was never developed. Today, three government registered historic buildings stand on the site, the old railway station, the station chief's residence and the Jabin Hotel. They are empty most of the time. In additions, a big old tree stands on the side of the old station. The small garden between them was in a mess and became a breeding ground of mosquitos.

The project team introduced new urban artefacts (Fig. 5) in the railway corridor (right "yellow box" in Fig. 1) to 1. Create a sequence of visual events (landmarks) that echoes to the collective memory of the "edge" of Guanshan (Lynch, 1960). 2. Make the corridor approachable and create visual sparks to attract people. The functions of the artefacts, however, are not limited to the historic use of this area.

Figure 5. Dormitory mural and old railway station side garden (before and after)

The most pertinent issue in the corridor is the uncomfortable condition of the railway side garden. Its sanitary condition indicates local people no longer have the capacity to maintain the greenery. Instead of replanting it, the project team chose to change it from wet-based to dry-based landscape and keep only four trees on the site. A line of sleepers was laid on the new gravel bed to give the garden a taste of an obsolete railway track. This newly created urban artefact not only solves the sanity and maintenance issues. It also introduces "direct experience". By stepping upon the sleepers, or by using it as a platform for train photography, the new function of the garden provides a connection to what the corridor was built upon.

The clean-up of the side garden exposes the view of Jabin Hotel across the road from the passing trains. In past 20 years, Jabin Hotel has been covered by sheet metals to protect its aging wooden exterior. The hotel has not been in commercial operation since the first-generation owner passed away in 2012. Once famous lines of roses along hotel perimeter now all died out. Rusts started to grow on the doors, exterior stairs and window trims. Without the fund for structure restoration, this project took two simple steps to make it friendly with surroundings again. First, the rusted surfaces were cleaned and repainted with historic green colour; second, the empty flower beds were removed and replace by long chairs with rose decoration pattern. The colour rearrangement makes this hotel in harmony with the nearby old train station. The street furniture provides a view of train passing by. It offers direct experience associating the hotel to the history of railway development.

Local high school students with architectural major were invited to take part in the implementation of the side garden and hotel exterior maintenance. They were also invited to take an in-depth survey of the hotel. The hope is that the younger generation will carry on the memory of the historic Guanshan to the future.

Back in the heydays, passengers on the train approaching Guanshan from the north would have seen a sequence of urban artefacts from the Japanese era: warehouses, dormitories, big trees, single residence of the station chief, Jabin Hotel and eventually the old train station. Travellers' description of the uniqueness of Guanshan experience was often started with the description of such visage. In order to recreate the linear experience of arriving Guanshan, the project renovated the naked cemented wall behind the gravel ground where the dormitory structures once stood. The wall is the exterior wall of the supermarket of farmer's association. Several public toilet entrances and a mud sink are attached to it. After reaching the conclusion that these functions are needed, the project team focused on how to change the perception of the wall. A cage was installed to seal the view of the mud sink. A famous local artisan was invited to paint a mural representing the railway worker's dormitory on the wall. The mural was painted in a section view according to historic colour scheme. Its proportion was purposely tweaked for selfies and for being seen afar. Individually, the mural attracts people approaching and staying around. Collectively, the dormitory mural, the single residence of the railway station chief, the big old tree, Jabin Hotel and the old train station reconstruct the historical visual experience of arriving Guanshan (https://www.youtube.com/watch?v=XCqyzr_2-bQ).

The mural turns out to be the most successful new urban artefact. Residents around the area constantly talk about how it reminds them the old days and changes the quality of the place. The visitors to the supermarket have increased. And the mural becomes a very popular scene of selfies in Guanshan.

b. The cultural corridor

The project team proposes to reinvent the steer axis of the government official's residences as the cultural corridor of Guanshan. From the functional aspect, it is a major deviation from the past. From the viewpoint of urban form, however, a change of use ensures the buildings carrying the memory of the town, will collectively find their place in the future.

After the Japanese left, a middle school and a vocational high school were established along this street axis by the Taiwanese government. At one end of the east-west running street is the new railway station. At the other end is the public vocational high school. The school is the highest education institution among the neighbouring counties. Further ahead, the mountain village of Bunun tribe is not far away. For decades after WWII, generations of students walking between the new train station and the schools, the official's residences they passed by every day, once the symbol of segregation, have long become the collective memory of Guanshan.

The function of the street as the official's residential sector has deteriorated overtime. Government policy changed and no longer provided housing for new public servants. Existing residents are reaching their eighties. Many wooden houses from the Japanese era are empty and in need of major renovation. Yet, no action has been taken since government finds no return for such investment.

By re-orienting the street axis to cultural activities, the project changes the purpose of the street from serving a diminishing population of former government employee to serving future generations in this region. Three steps were taken in this corridor: 1. An Art installation on an open space reflecting multi-racial culture and history of this region. 2. Renovation and utilization of an empty house from Japanese era to hold cultural events. 3. The renovation of several shopfronts to reinforce the historical image of the street.

The very reason for the creation of Guanshan Township was to control native Taiwanese. Bunun people living in the Central Mountain were the Japanese government's primary target. Over the years, Bunun people were displaced from their deep mountain settlements and forced to settle in the shallow mountain village nearby Guanshan. The relocation of Bunun people also brought their culture to Guanshan's daily life. The art installation, a woodwork composition representing the stretching clouds and the serpentine, was designed by the team and built by a Bunun artisan and high school students. It was placed on the open space in the mid-section of the street. Function wise, the art installation serves as benches in the park. They are designed to allow people to sit, to lie down, to chat face to face or even to picnic together. Icon wise, serpentine carries the meaning of friendship in Bunun culture and the stretching cloud by the hill is ubiquitous in Huatung Valley. The open space was there only because the old buildings standing on it deteriorated and fell apart. It created a breathing space, similar to Geddes's notion of "conservative surgery"(1915), to the development of the town. The new urban artefact, an art installation created from indigenous elements of Guanshan, is to give a sense of prestige and permanency to the open space. Hoping the open space will eventually become a permanent existence in Guanshan's townscape (Fig. 6).

Figure 6. Art installation in the open space of the cultural corridor

Figure 7. Events and actives in the cultural hub (renovated Japanese house)

Figure 8. Examples of shopfront renovation (signage, semi-open space and street furniture)

Across the street from the open space, an empty house managed by the town office was renovated. The house was constructed during the Japanese era. Later on, several spaces were added to the Japanese-styled structure. The exterior wall was installed with signboard for posters of events. Semi-open front yard was furbished with lights and benches for woodworking. The wall of entrance hall was painted as black board and furnished with desks and chairs for meeting and discussion. The front Japanese room was cleaned and stocked with toys for children while their parents take part in the house's event. The rear Japanese room was furnished with mattress to accommodate temporary stay. The original kitchen and dining space was placed with rows of chairs and a projector for lecture up to 20 people. Neighbours, artisans, teachers and students were invited to take part in the events hold in this renovated house (Fig. 7). The facility functioned well and the reaction was very positive.

Finally, several privately-owned buildings were chosen for government sponsored storefront renovation. Their typologies all bear significance to Guanshan's history. The objective of the renovation is to create a holistic image of Guanshan. The project did so by renovating storefront based on historic images, introducing storefront furniture and redesigning the business signage (Fig 8). Recent research (Zheng, 2014) has shown that street furniture give visitors more places to rest, resulting in longer stay. All the renovation works were carried out by local craftsmen - another kind of “direct experience”. The shop owners were very happy with the end products of the renovations.

Conclusions

In a time of drastic societal changes, many historic buildings can no longer be sustained by its original use. There are cases where the historic event is extremely important that the artefact associated to it should be kept at all cost. There are far more cases where such significance cannot be found. It is always a debate if there is a coherence approach to treat these everyday historic structures.

In this project, Rossi’s view of city as urban objects was taken as guidance. The creative forms were associated with the historic context yet their functions were allowed to change. It was the “direct experience” offered by the new urban artefacts reconnecting people with the memory of the past. The appreciation to people’s memory and the convenience of modern amenities of the renovated spaces bring high regard from people of all demographic groups in Guanshan.

In months after the completion of the project, the limitation of the townscape improvement is gradually surfaced: 1. Local civic groups do not have enough capacity to operate and maintain the cultural hub (the renovated house). And the government regulations would not allow business entity, even cultural related ones, to operate in it. It results in low utility rate of the space. 2. Local residents like the changes of townscape. Yet, people think, for any long term effect, the concern on local healthcare and education infrastructure need to be addressed. Good design can help community revitalization. But it is people that make changes. In addition to a quality built environment, sound regulatory environment and social infrastructure are still needed to make the changes sustainable.

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The Integration of Urban Agriculture and the Socio-Economic Landscape of Future Cities

Andrew Jenkins[1], Professor Gregg Keeffe[1]

[1] School of Natural and Built Environment, Queen's University Belfast, Belfast, Northern Ireland, ajenkins02@qub.ac.uk/g.keeffe@qub.ac.uk

Abstract: Cities rely upon the provision of imported foods in order to feed their large populations. As a result, the ecological footprint of cities is far greater than their geographical areas. Through the integration of facade and roof-based food systems, agriculture within urban environments has the ability to grow vast amounts of food upon some of the most underused and undervalued areas of the built environment. Such large-scale agricultural systems would not only reduce a city's ecological footprint by reducing the need for imported foods, but they would also engage with the city at an economic and social level. The following paper aims to understand the additional positive impacts of urban agriculture - such as reduce air pollution, decrease depression, promote healthy lifestyles and create jobs - and postulates how such impacts might affect the physical health, mental well-being and financial security of urban populations. Urban agriculture is a viable driver of environmental change, but it is also a catalyst for social and economic reform.

Keywords: Urban Agriculture, Ecosystem Services, Social, Economic, Architecture

Introduction

Urban agriculture is capable of producing large volumes of crops upon the surface area of cities through the integration of horizontal and vertical based food systems (Jenkins, et al., 2015). In doing so, a multitude of supporting services are created such as air filtration, psychological restoration, and the creation of jobs. The following paper aims to understand the role these supporting services play in the physical, psychological and financial well-being of urban populations, and forms an overview of the different ways in which urban agriculture can benefit cities. The research, in most cases, does not aim to quantify these impacts but instead discusses the linkages between prevalent issues within cities and the additional services provided by urban agriculture. Although the research discusses the economics of urban agriculture, it is not the role of this paper to develop robust economic models. Instead, the paper aims to use simple methods of analysis to calculate the impact on local economies and the number of jobs created.

Global Food Demand

At some point during 2010 and 2011, the world's population surpassed 7 billion people for the first time in human history (ESA, 2015). As a result, a single hectare of agricultural land will need to supply enough food for 6.7 people per annum by 2050, whereas the same area of land in 1970 had only to produce enough food for 2.6 people (FAO, 2012).

The relationship between agricultural land share and food production is not always a direct one however. Due to increased economic prosperity and changing dietary habits, it is estimated that food production will need to increase by 70 per cent in developed countries and 100 per cent in developing countries by 2050, when referring to production values of 2005 through to 2007 (Bruinsma, 2009). If these estimations are correct, the increase in production will have to be met regardless of changing climates and concerns over energy security, without the cultivation of additional land and without further damage to essential ecosystem services (The Royal Society, 2009).

Ecosystem Services

Ecosystem services are described as the benefits that people obtain from ecosystems (Millennium Ecosystem Assessment, 2005). These include, but are not limited to, food, natural fibres, purification of water, air filtration, regulation of pests, pollination, microclimate regulation, medicinal substances, noise reduction, carbon sequestration, nutrient cycling, open space, and protection from natural hazards such as floods.

Since the inception of the first cities, the dependence on ecosystem services has not changed. The city of Uruk, founded by the Sumerians in 3500BC, was dependent on the flooding of the River Tigris and River Euphrates to enhance the fertility of their soils. However, this flooding was unpredictable and so led to unpredictable harvests. To combat this, the city constructed the first artificial landscapes; building large levees to contain the river and constructed sophisticated irrigation systems to distribute the water evenly to outlying farms (Steel, 2013). By moulding the natural world to suit their needs the Sumerians could predict their harvests more accurately, enabling them to hold a larger static population and in doing so, establish the basic ground rules of urban civilisation.

In 3500BC, city and nature combined to form the ‘city-state’, exemplifying the connection between prosperity and ecosystem services. Since the invention of global trade, however, these ecosystem services have been displaced well beyond the civic boundaries of today's cities. This disconnection not only shields urban populations from the vital role nature plays in their lives, but it also separates the very processes that are needed to keep people alive, happy and healthy from where they are most needed; cities.

Urban Health

Urbanisation is a process closely linked with economic development, but its impact on health and wellbeing can, in some instances, be dramatic. Non-communicable diseases (NCDs) - mainly cardiovascular diseases, chronic respiratory diseases, cancers, and diabetes - are the world’s biggest killers. More than 36 million people die annually from NCDs accounting for 63 per cent of global deaths each year (WHO, 2013). The primary causes in most cases of premature death from NCDs are tobacco use, an unhealthy diet, physical inactivity and the excessive consumption of alcohol. Although urban development cannot be held responsible for these risk factors, the urban context is associated with the adoption of lifestyles that favour the development of NCDs (Van de Poel, et al., 2009). This is due in part to increased exposure to outdoor air pollution, overcrowding, crime, stressful work and social isolation, as well as the increased consumption of salt and high sugar foods, reduced physical activity, and increased tobacco use. All of which increase the risk of hypertension and obesity, leading to increases in heart disease, strokes, certain cancers and diabetes (Mendez et al., 2009).

Depression and Anxiety

Psychiatric disorders, including stress and anxiety amongst other conditions, are one area in which the urban context can dramatically affect the wellbeing of an individual. Peen, et al., (2009) discovered that the presence of psychological conditions, on average, were 38 per cent higher in urban areas than in rural areas. This also included for depression and anxiety, which were 39 per cent 21 per cent higher respectively. Within the UK, the total cost of depression and anxiety in 2007 was £16.4 billion. These psychological disorders, as a result of city living need addressing to help increase the mental well-being of urban populations, reduce the economic strain brought about by these conditions, and to reduce the number of those affected developing more serious physical conditions.

Air Pollution

Another factor affecting physical wellbeing within cities is exposure to air pollution; compromised of particulate matter, ozone, nitrogen dioxide and sulphur dioxide. Urban air pollution can be responsible for such problems as Chronic Obstructive Pulmonary Disease (COPD), which is a collection of lung diseases including chronic bronchitis, emphysema and chronic obstructive airways disease. Within the UK, air pollution is estimated to reduce life expectancy by seven to eight months (Environmental Audit Committee, 2010) and within Europe, over 100,000 deaths are recorded per year as a direct result of exposure to fine particulate matter (WHO, 2003). The total direct cost of COPD to the National Health Service in the UK is over £800 million per annum, with the indirect cost of lost productivity to employers and the economy estimated at £3.8 billion a year (NHS Medical Directorate, 2012). The total cost of health problems related specifically to particulate matter is even higher; estimated to be between £9.1 and 21.4 billion per annum (DEFRA, 2007).

High levels of air pollution can exacerbate symptoms found within asthma sufferers and in some cases, can lead to fatal asthma attacks, which currently accounts for approximately 250,000 annual deaths worldwide. (Bousquet, et al., 2007). It is expected that urban air quality will continue to deteriorate globally with air pollution projected to become the top cause of environmentally related deaths worldwide by 2050 (OECD, 2012).

Obesity and Diabetes

Although not necessarily exacerbated within urban areas, (Peytremann-Bridevaux, et al., 2007; Befort, et al., 2012) obesity is quickly becoming a global problem. Diabetes, on the other hand, is projected to increase globally as a result of urbanisation (Wild et al., 2004). In 2012, an estimated 62 per cent of adults were overweight in England; 24.7 per cent of which were obese, with 2.4 per cent noted as severely obese (Public Health England, 2014a). In 2013, 2.7 million adults were diagnosed with diabetes in England; an increase of 137,000 people from the previous year (Prescribing and Primary Care Team, 2013). Within the UK, 10,000 premature deaths per annum are linked to obesity (Faculty of Public Health, n/d) with type 2 diabetes accounting for 23,300 deaths per annum in England alone (Public Health England, 2014b). Obesity costs the UK £4.2 billion pounds per annum and type 2 diabetes and its related effects on healthcare and the economy account for expenditures of £13 billion per year (Public Health England, 2014b). Only through challenging the risk factors associated with NCDs - specifically physical inactivity and poor diets - will the prevalence of obesity and diabetes start to decline, bringing with it healthier populations who live longer.

The Impact of Urban Agriculture

Due to the linkages between lifestyle choices and the primary risk factors of NCDs, the majority of premature deaths are largely preventable by tackling the associated risks (WHO, 2013). Although it can be argued that these risks cannot be directly resolved through urban agriculture, the integration of agriculture within urban environments can promote alternative lifestyles to those currently offered to help reduce their impact.

Human well-being consists of security, the basic materials for a viable livelihood (food, shelter, clothing, energy, etc., or the income necessary to purchase them), freedom, choice, good health, and good social-cultural relations (Millennium Ecosystem Assessment, 2005). Ultimately, all aspects of human life are defined by the access to ecosystem services such as food, clean water and fresh air. It can, therefore, be argued that the wellbeing of mankind is directly proportional to the health of the biosphere.

If the above factors of human well-being are combined with the primary causes of NCDs, three distinct categories emerge with which the impact of urban agriculture can qualified; physical health, psychological well-being, and financial security. The following will discuss how urban agriculture can benefit society in these three key areas.

Physical Health - Food Production

The most prevalent way in which urban agriculture can affect physical health is through the improved access to organic foods. In an effort to quantify city-wide food production, the authors of this paper designed and constructed a working elevated aquaponic food system in 2012/13. This system was constructed within a disused mill in Manchester, England and was capable of producing 16,500 crops per annum (Jenkins, et al., 2015). As part of this experiment a food producing facade prototype was also developed to explore the possibilities of vertical growing upon buildings (Jenkins, et al., 2014). Taking the crop production metrics of these two systems - 26.66 crops/m2 and 15 crops/m2 respectively, it was possible to calculate city-wide food production, using the city of Manchester, England as a case study. Through the use of three-dimensional modelling, an annual city-wide daylight study was produced and the vertical and horizontal data from the elevated aquaponic food system and façade prototype was applied. The resulting data concluded that the city centre of Manchester was capable of growing an estimated 180.4 million crops per year upon its vertical and horizontal surfaces (Jenkins, et al., 2015). Such production levels of organic foods would at the very least promote an increase in fruit and vegetable consumption, leading to improved urban diets.

Physical Health - Air Pollution

To progress this research further the same area studied for the daylight analysis of Manchester was investigated further to analyse the provision of green space within the city. It can be seen that the current proportion of green space within the city is particularly low (see Figure. 1). The city centre of Manchester covers an area approximately 402.3 hectares in size, of which green space accounts for only 24.2 hectares; approximately 6 per cent. Urban green space is key to improving air quality as it not only helps sequester carbon and produce oxygen, but also aids in the reduction of particulate matter, and can in some cases absorb ozone, nitrogen dioxide and sulphur dioxide

Taking into account only horizontal food systems upon flat roofs in Manchester, urban agriculture would add an additional 76 hectares of green space to the study area; increasing total green space by 314 per cent (see Figure 1). If vertical growing was also taken into consideration another 94 hectares of green space would be added - taking into account the reduction in crops/m2 compared with horizontal systems. Therefore, the total cumulative addition of green space within the city through the integration of urban agriculture would be 170 hectares; an increase of 702 per cent - making the city eight times more efficient at processing air pollution. The improvement of air quality within urban environments will not only better protect those suffering from respiratory diseases but it could also lead to the reduction in the development of respiratory diseases within cities.

Figure 1. Current green space within Manchester city centre (left) with possible green space (right)

Psychological and Physiological Wellbeing

Natural environments are said to have restorative qualities, which help the human body recover after periods of stress. This theory suggests that humans evolved a positive psychological response to unthreatening natural environments to allow fast and effective recovery from the stress response. It is believed that modern humans retained this positive response to natural environments and it is still as crucial today as it was many millennia ago (Ulrich, 1993). In this context, restoration is defined as 'the process of recovering physiological, psychological and social resources that have become diminished in efforts to meet the demands of everyday life' (Hartig, 2007). These restorative qualities include, but are not limited to, the reduction in blood pressure, levelling of heart rate, reduction in muscle tension, reduction in stress hormone levels and the strengthening of the immune system (Hartig, et al., 2003; Park, et al., 2010). This natural connection between humans and ecosystems is so strong, that restoration can even be achieved through non-tangible experiences - i.e. when viewed through a window - allowing people the opportunity for 'micro-restoration' in their everyday indoor environments. Although brief, these micro-experiences can combine to form measurable cumulative benefits (Kaplan, 1993).

The introduction of urban agriculture to the city of Manchester, England would add an additional 170 hectares of restorative infrastructure to the city. Although the majority of this newly created foliage would be inaccessible to most, the views out from buildings within the city would be transformed into a sea of vegetation spreading across rooftops, spilling down facades and engaging with the public realm. This in itself would bring with it a multitude of opportunities for micro-restoration throughout the day as well as opportunities for full psychological restoration through the creation of vegetative social spaces and centres for commerce.

Physical activity, although primarily linked with physiological well-being, has a profound effect on the psychological wellbeing of an individual. Exercise is key part of mental health but within urban environments, exercise in the traditional sense is hard to fit into daily life. However, even brief five-minute spells of green exercise can lead to large benefits (Barton, et al., 2010). Consequently, green exercise projects are increasingly seen as a valuable form of treatment for mental health problems.

Financial Security

It is estimated that the city of Manchester can grow approximately 180 million crops per annum, achieving a sale value of between £360 million and £720 million per year (Jenkins, et al., 2015). Such massive levels of crop production would require a substantial workforce. For the proceeding approximation of job creation within the city of Manchester the lower of the two estimates will be used for annual turnover; i.e. £360 million. This value is the sum of profit, human capital and running costs, which are extremely sensitive to external pressures and complex to calculate. Hence, simple existing information will be used to inform this data.

Tesco is a large supermarket chain in the UK and reported operational profits of 9.2 per cent in 2015 (Tesco, 2015). If this is applied to the projected turnover of urban agriculture in Manchester, approximately £33 million would be set aside as profit for future investment. The percentage spent on human capital by larger companies is approximately 70 per cent (Human Capital Management Institute, n/d); i.e. £229 million per annum. The remainder would cover utility costs, cost of repairs etc. at a cost of £98 million per annum. If the cost of human capital is compared to the average distribution of wages per 1 per cent of population within the UK (HMRC, 2015) the job creation of urban agriculture within Manchester can be calculated. For example, the 1st percentile of the labour force in the UK earns, on average, £8,370 per annum and the 99th percentile of the workforce earns, on average, £150,000 per annum (HMRC, 2015). By using the same proportions of wage spend per 1 per cent of population and applying it to the workforce of urban agriculture within Manchester, it can be calculated that 8,385 jobs would be created within the city at varying levels of importance and income. For the purposes of this exercise a sample of the data has been provided indicating 84.7 jobs are created for every one per cent of workforce, equalling 8,385 jobs in total (see Table 1). It should be noted that the top one per cent of earners have been removed from the study due to extremely high wages.

Table 1. Sample data of job creation when applied to percentile earnings in UK (UA=Urban Agriculture)

Percentile	Annual Wage	Percentage of wage bill	Money for UA Job Creation	Jobs created in UA
1st	£8,370	0.31	£708,949	84.7
50th	£21,000	0.78	£1,778,726	84.7
99th	£150,000	5.55	£12,705,188	84.7

Conclusions

By the year 2050 it is expected that 66.4 per cent of the world's population will be living in cities (ESA, 2014). Although cites are primarily man-made, techno-centric environments, they depend entirely on ecosystem services well beyond their civic boundaries. If cities are to become more sustainable and resilient to change it is likely that they will have to engage with ecosystem services at increasingly localised levels. Urban agriculture, in most respects, provides a solution to producing food where demand is highest. Although the food produced by urban food systems through non-intensive farming techniques (i.e. natural lit polytunnels and facades) will never be able to meet the full demands of urban populations, it can help reduce the need for imported foods, as well as reduce the need to cultivate natural environments elsewhere.

Air pollution, poor diets, physical inactivity, depression, anxiety and financial insecurity are all issues which affect the wellbeing of urban populations and urban agriculture can help remedy these issues to varying degrees. The integration of urban agriculture can greatly increase vegetation within the city, improving air quality and reducing the probability of urban populations suffering asthma attacks or developing chronic obstructive pulmonary diseases. Additional green vegetation within cities, even if not entirely accessible by the public can aid in reducing depression and anxiety through the restorative healing power of natural landscapes, and can aid in promoting exercise through the use of green corridors and the provision of engaging public spaces. Finally, urban agriculture can produce vast quantities of fresh organic food, promoting healthier diets, reducing obesity, and creating thousands of new jobs within greener, more engaging cities.

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Design to Thrive

Empowering local people through the planning process: The emerging practice of 'Place Planning' and its contribution to community well-being in Wales

Matthew Jones[1], Amanda Spence[2]

[1] Department of Architecture and the Built Environment, Faculty of Environment and Technology, University of the West of England, Bristol, UK, matthew32.jones@uwe.ac.uk;
[2] Design Commission for Wales, Cardiff, UK, amanda.spence@dcfw.org

Abstract: The past twenty years has seen UK Government aspiring to put greater power in the hands of local people. In England, the 2011 Localism Act and 2012 National Planning Policy Framework have created new opportunities for local people to influence development. The Welsh Government has taken its own stance: the Planning Act 2015 (Wales); the Well-being of Future Generations (Wales) Act 2015 and the Active Travel (Wales) Act 2013 commit local authorities to improving social, economic, cultural and environmental well-being. Alongside these top-down processes, there is an emerging strategy to further engage local people in influencing the quality of their places and the well-being of their communities. A critical review of two tools designed to facilitate the Place Planning process in Wales is presented. Both tools help to increase opportunities for local people to have a voice in the planning process, and for the people who know places best to influence their well-being. However, questions are raised about the capacity and aspirations of communities to help deliver Place Plans, and assess the pressures on overburdened, under-resourced local authorities. Importantly, the increasing role of community-led initiatives has consequences for the role of designers and the skills they can contribute to place-making and well-being.

Keywords: Place, planning, well-being, community, Wales

Introduction

This is a critical point in time for our communities, with drastic reductions in local government spending placing greater levels of responsibility for the future of communities in the hands of their inhabitants. Increasingly stretched Local Authorities across the UK are focused on providing essential and statutory services, while planning and development services have faced cuts of 46% between 2010 and 2014 (National Audit Office, 2014, p4).

While in England the *Localism Act (2011)* has created new opportunities for local people to influence development, in Wales the *Planning (Wales) Act 2015*, the *Active Travel (Wales) Act 2013* and the *Well-being of Future Generations (Wales) Act 2015* have committed local authorities to improving social, economic, cultural and environmental well-being. Alongside these strategic policies, there is an emerging approach to further engage local people in influencing the future of their built environment through the development of 'Place Plans', led and authored by local communities and adopted as Supplementary Planning Guidance. These policies present a unique opportunity to redistribute knowledge and decision-making power to local people, offering the opportunity for communities to 'reclaim the initiative' and for the people who know their places best to inform their future.

In response to these agendas, this paper explores the emerging Place Planning process in Wales and its potential to empower communities to take control of their future and to increase community well-being. It is suggested that in order to enable local people to understand their place and make a tangible difference to it, new methodological approaches and tools are needed. The innovative 'Shape My Town' method of analysis, designed to enable community-led plan making in Wales and beyond, is critically reviewed. Developed by Coombs Jones Architects and Design Commission for Wales (DCFW), it is the first Place Planning tool to be developed and tested in Wales. It offers an approach founded on the need to construct an evidence base, created through analysis of the built environment, to inform community-led decision-making. Two iterations are discussed: 'Shape My Town', a freely available web-based toolkit giving local people the tools, resources and inspiration to help shape the future of their built environments; and 'Shape My Brecon Beacons', a bespoke evolution of the tool developed for the Brecon Beacons National Park Authority that extends the tool to include community well-being and cohesion.

We argue that these tools, founded on principles derived from urban design research, help to increase opportunities for local people to 'reclaim the initiative' in the planning process and for the people who know places best to influence their future and well-being. We conclude by discussing the opportunities and challenges of transferring plan-making to local communities and the impact of this on the role of designers in contributing to place-making and well-being. While the complex interplay of localism and austerity present *"an opportunity for progressive urban design and a rupture in business-as-usual urban development"* (Gray, 2016, p.4), these challenges have significant consequences for how designers conceive the urban environment and the skills they can contribute to place-making.

Community-led planning and well-being

Recent policy in the UK has seen a shift toward increasing participation in decision-making. The UK Government's 'Big Society' concept and the *Localism Act*, which gained Royal Assent in November 2012, is giving local people more decision-making powers and offering communities opportunities to shape their environment by developing local plans. Top-down is being replaced by bottom-up, with the aim of "*reinvigorating the most local forms of government – parish, town and community councils – allowing them to take control of key local processes, assets and services tailored to the needs of local residents*" (RIBA, 2011, p.7).

The devolved Welsh Government has taken its own approach. Welsh Government's '*Regeneration of Town Centres'* report recommends that within the framework of a local authority's Local Development Plan (LDP), individual communities should have a comprehensive plan in place developed by a partnership of stakeholders and the community (National Assembly for Wales Enterprise and Business Committee, 2012). The *Planning (Wales) Act 2015* similarly requires increased participation and public engagement in development planning. Alongside the accompanying *Positive Planning Implementation Plan (2015),* the Act introduced the notion of 'Place Plans' as Supplementary Planning Guidance, led and authored by local communities. Welsh Government's *Planning Policy Wales* states that, *'Selective use of Supplementary Planning Guidance (SPG) is a means of setting out more detailed thematic or site specific guidance on the way in which the policies of an LDP are to be interpreted and applied in particular circumstances or areas'* (Welsh Government, 2015 p.21). This represents a shift toward greater emphasis on place and community engagement in the plan-making process, giving individuals and groups a greater and more meaningful impact on the future of the places in which they live, work and play.

Alongside the devolution of plan-making power, Welsh Government has placed Well-being at the heart of Government policy. The *Well-being of Future Generations (Wales) Act 2015* and *Active Travel (Wales) Act 2013*, commit local authorities to improving social, economic, cultural and environmental well-being. The *Future Generations Act* introduces seven well-being goals, creating a shared vision for public bodies to work towards to support individuals and communities to sustain and improve their health and well-being. The five 'Ways of Working' outlined in the Act encourage integration, collaboration and involvement and place well-being at the heart of regeneration policy (see table 1).

Together, these Acts create an environment in which local people can have an increased role in considering the well-being of their place. Taking control of the future of their place can empower communities to bring into consciousness the conditions that shape their place in their world; this self-determination is linked to an increased sense of well-being, purpose and community cohesion (Deci and Ryan, 1985).

Table 1: The seven well-being goals and five ways of working described in the *Well-being of Future Generations (Wales) Act 2015*

Seven Well-being Goals	Five 'Ways of Working'
A globally responsive Wales	Long-term
A prosperous Wales	Prevention
A resilient Wales	Integration
A healthier Wales	Collaboration
A more Equal Wales	Involvement
A Wales of cohesive communities	
A Wales of vibrant culture and thriving Welsh language	

The 'Shape My Town' method

In this context, this paper illustrates the use of the innovative 'Shape My Town' method (www.shapemytown.org), developed to encourage and enable community-led, local planning in Wales and beyond.

The method was developed to reflect the importance of understanding the built environment in creating successful places and to promote a move toward greater consideration of place-making and distinctiveness in new development. Welsh Government has identified *"the physical quality of the town and its rural area"* as a vital component in developing *"vital and vibrant places"* (Welsh Government, 2012 p.4). Research by CABE suggests 87% of people agree that the quality of buildings and public spaces have a direct impact on the way they feel (CABE, 2002), and research by Gehl (2004) has similarly linked the quality of public space to social use and liveliness. It has also been demonstrated that good quality design plays a vital role in enhancing the well-being of inhabitants, strengthening community, improving social and physical health, and increasing civic engagement (Knox & Meier, 2009).

Created by Coombs Jones and DCFW, 'Shape My Town' builds on a body of work understanding the physical character of a place, including DCFW's publication '*My Square Mile*' and '*Ruthin: Market Town of the Future*', an award-winning community-led town planning project. The method provides an accessible web-based toolkit of information, guides and ideas to inspire and support community groups who want to play a part in shaping the future of their places. The target audience is predominantly non-professional and the tool offers a simplified set of questions to provoke discussion and analysis of urban design issues. The method consists of five phases that lead participants through setting up a plan team, building an evidence base for decision making, developing a vision, delivering a place plan and monitoring progress, summarised in Table 2. Best practice case studies, downloadable guidance and resources to help facilitate workshops and activities supplement the analytical tool.

The methods of analysis promote an approach to the understanding of places that is focused on the built environment. The primary aim is to reveal the sense of place and the components that give a place its character; as Powe and Hart (2016) identify, gaining an understanding of how a place has been affected by history and geography is vital in planning for its future. The analysis prompts consideration of the built environment at a range of settlement scales. The method draws on research that is morphological (Lynch, 1960), historical and visual (Cullen, 1961 & Worskett, 1969), multi-scalar (MVRDV, 2002) and people oriented (Gehl, 2004). While the above approaches tend to focus on one aspect of place-making, the Shape My Town approach is a qualitative multi-dimensional analysis that gathers, processes and reconstructs evidence derived from experiential, photographic, graphic and statistical surveys. The tool encourages local people to build an evidence base for change in their community through analysis of urban design issues, sense of place and distinctiveness, by working at a variety of scales, each with a series of guidance notes and associated ‘questions to ask’:

- Landscape: Setting, views, skyline, edges, parks and green space.
- Townscape: Heritage and history, form and layout, buildings and scale, and materials and detail.
- Streetscape: Public spaces, Streets and lanes, Furniture and surfaces.

Through evaluation and analysis of the information gathered and comparison to other places, key strengths, weaknesses and opportunities for improvement are revealed and taken forward into a place plan.

Pilot projects: Increasing community coherence

The tool was tested through pilot studies in two communities in south Wales: Abergavenny, a relatively sizable and prosperous market town in Monmouthshire, and Ynysybwl, a village in the post-industrial South Wales Valleys. In a day-long workshop in each location, members of local community groups and councils came together to test the evidence-building phase of the toolkit. Feedback was collected through observation of the workshop in progress and use of a questionnaire to gather formal feedback from participants. This process revealed a number of key issues that were addressed in amendments to the toolkit.

The emphasis on built environment did not allow exploration of community facilities and the relationships between community groups in any detail. It gave a specific focus to the evidence gathered that excluded vital aspects of community cohesion and how the community functions within its environment. The well-being of a community - the way health, educational, cultural, housing, employment, leisure and social needs are met - are important considerations in the planning process and by neglecting these aspects the tool was limited in its application. In many cases what is needed is not new buildings or public spaces but a greater consideration of how people live in a place and how their social needs are catered for.

Table 2: Comparing the Shape My Town and Shape My Brecon Beacons process

Stages of the process	Shape My Town	Shape My Brecon Beacons
Getting Started	-Setting up a town team -Working with the Local Authority -Working with the community	-Set up a place plan team -Form a relationship with the local authority - Reach out to the wider community
Gathering evidence	- Landscape - Townscape -Streetscape	-Context and setting -People and place -Buildings and facilities -Life between buildings
Evaluating the evidence	-Analysing and comparing your town -Evaluating distinctiveness	-Drawing out findings -Engaging the wider community
Writing a plan	-Preparing a plan -Consulting planning policy -Identifying issues -Your vision -Developing a framework -Measuring success	-Preparing a plan -Working with the local authority -Developing a vision -Developing a delivery framework
Agreeing and implementing a plan		-Agreeing your action plan -Stakeholder agreement -Agreeing the plan as Supplementary Planning Guidance -Monitoring and review

Considering community well-being: Shape My Brecon Beacons

Following development of the tool and pilot testing, Welsh Government announced a shift in policy toward greater consideration of health and well-being. Subsequent development of the tool has reflected the changing aspirations and remit of local authorities and the need for greater consideration of well-being as part of the planning process. In 2016 Welsh Government approached local authorities in Wales to develop concepts for place planning in their locale in light of these changes to policy. Working alongside the Brecon Beacons National Park Authority, The Shape My Town method was used as basis for a bespoke version of the tool for use in the National Park. In response to the pilot projects and the changing policy landscape, the scope of the tool was extended to further explore the function and well-being of a community, taking the emphasis away from the built environment. A further step in the development of the tool was to link the outcome of the tool to planning policy and enable emerging Place Plans to be adopted as Supplementary Planning Guidance. To achieve this, the tool emphasised the importance of positive relationships with the local authority and identified the role of planning officers in guiding and steering the plan-making process. Here, local authorities act as facilitators and mediators working with local people rather than implementing top down policy and procedure. This further addressed a concern with monitoring the use and effectiveness of the original web based tool; due to being freely available, it had proved difficult to track use and application. Through the involvement of the local authority in the process, the number and location of communities undertaking place plans in the authority area can be tracked and their development monitored.

The three analysis themes (landscape, townscape and streetscape) were reorganised to integrate community and well-being concerns, resulting in four new headings: Context and setting; People and Place; Buildings and Facilities and Life Between Buildings. As table 3 demonstrates, this reorganisation embeds well-being within the analytical framework to a greater extent that the original Shape My Town web tool.

Table 3: Potential well-being benefits addressed in Shape My Town and Shape My Brecon Beacons

Shape My Town	Shape My Brecon Beacons
Landscape: - Ecology and biodiversity - Physical health - Mental health	Context and Setting: - Ecology and biodiversity - Physical health - Mental health - Coping with climate change - Cultural identity
Townscape: - Cultural identity	People and Place: - Inclusivity and accessibility - Employment - Education - Health - Cohesive communities
Streetscape: - Spaces for social interaction - Accessibility - Connectivity - Active travel	Buildings and Facilities: - Economy - Housing equality - Low-carbon living - Coping with climate change - Environmental sustainability
	Life Between Buildings: - Accessibility - Connectivity - Spaces for social interaction - Active travel

While still founded on principles of place-making and analysis that works across a range of scales, the reorganisation encourages greater consideration of demographics, employment, public services and community services. The revised themes give a broad picture of the social well-being of a place and introduce a further layer of analysis to the method using readily available statistical data. Similarly, consideration of housing provision and tenure, access and transport connections extends the scope of the analysis and aligns the outcomes of evidence building more closely to planning policy objectives.

Conclusion: Reflecting on the process

The emerging importance of health as a policy driver is leading countries to explore mechanisms for improving community well-being. Initially a top down process, governments are increasingly searching for ways to support communities to improve their own social, economic, environmental and cultural well-being.

Fully developed in England and emerging in Wales, localised planning processes will create the opportunity for communities to produce their own place-specific plans, manage services and build small developments. This empowerment of local people to lead regeneration processes could see plans being created by people who know their place best. Tools such as Shape My Town offer benefits of a strong foundation of evidence, built on local knowledge and understanding of local issues.

To succeed at plan-making and realise projects, communities need to be able to mobilise a range of skills and resources. While this puts communities in charge of their future, it requires activation of social capital, whereby community members become fundraisers, coordinators and 'champions'. Facing deep-cutting austerity measures, there exists a lack of capacity within Local Authorities to facilitate this and provide the necessary support to communities (Powe et al, 2015). There is currently limited financial support available for this type of community development and local people are being asked to shoulder the burden. Where there is no expert involvement, tools and resources such as Shape My Town provide a way to fill this gap and guide local people through a methodical process, enabling Local Authorities to do more with less.

However, with limited expert input, there is a risk that planning processes led solely by local people could result in narrowed vision and insularity (Powe, 2016). While local people arguably know their place best, external experts can act as mediator, provocateur, initiator and consultant and offer routes to wider participation and successful implementation (Petrescu et al, 2016). Additionally, experts can help to promote active citizenship, entrepreneurship and capacity building to achieve change (Herbert-Cheshire & Higgins, 2003). Built environment design professionals can contribute creative problem-solving skills and an innovative approach to place-planning which is likely to be missing from community groups and cannot be replaced by a toolkit. The long-term value which expert consultants can bring to plan-making should not be underestimated or compromised by short-term cost cutting.

In the context of an evolving planning system in Wales, the Welsh Government and Local Authorities have an opportunity to engage with local communities through Place Plans so that they can make a real difference to their own environment and well-being. Tools such as Shape My Town can enable this process to happen with stretched Local Authority resources, but to maximise the impact and long-term value of Place Plans, investment in professional design and planning skills should not be overlooked.

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Toward an Asian Sustainable Urbanism: A Comparative Study of Model Eco-city Projects in Japan and China

Zhongjie Lin[1]

[1] Associate Professor of Architecture and Urbanism, Director of Master of Urban Design program, School of Architecture, University of North Carolina at Charlotte.

Abstract: Asia has seen rapid development of eco-city led by governmental initiatives. The Japanese government continues to expand its "Eco-Model Cities" program, while in China, hundreds of towns have laid out their plans to become an eco-city, inspired by the national directives and high-profiled demonstration projects. In both countries, the eco-city is promoted as innovative urban policy under the agenda of sustainable urbanization and restructuring post-industrial economy. This paper compares the planning and development of model eco-cities in Japan and China, using Kitakyushu and Tianjin for case studies to examine their common and contrasting approaches to ecological urbanism, their respective design strategies and technological measures, the relationship between the eco-city building and local economic development, and the roles played by the governments and the private sector in this effort. Through the analysis of the policies and implementations of eco-city in both countries, this paper aims to offer a critical insight into the changing ideas of urbanity in Asian society, and engage discussion of the global issues of sustainable urbanism.

Keywords: Eco-city, sustainable urbanism, Kitakyushu, Tianjin Eco-city, Asian urbanization

Introduction

Although the concept "Eco-city" has been discussed and promoted for several decades, it was in the last ten years that we started to see an increasing number of large-scale projects translating it into practice. Eco-city is now a global phenomenon, yet Asia shows particularly notable development with strong governmental intervention, and witnessed ambitious, systematic national initiatives to build exemplary eco-cities. In Japan, the central government launched the "Eco-Town Project" initiative in 1997, then turned it into a more comprehensive "Eco-Model Cities" scheme announced at the 2008 G8 Summit in Hokkaido. So far twenty-three cities have been designated as Eco-Model Cities, ranging from large cities like Yokohama to small towns like Minamata. Financial incentives are provided to undertake major urban restructuring, low-carbon developments, and sustainable industries.

Arguably the most ambitious eco-city program, at least in terms of the number of initiatives and scale of projects, is currently taking place in China, where more than 100 eco-new towns are under development and some 259 existing cities have declared their intention to become an "eco-city" or "low-carbon city" (China Urban Sciences Research Council, 2011). The central government has created a number of high-profiled eco-city demo projects, such as Dongtan Eco-city in 2004 and Tianjin Eco-city in 2007. Eco-cities are promoted as innovative urban policy strategies and practices under the overarching paradigm of "ecological modernization," which seeks to de-couple economic growth from environmental degradation by incentivizing low-carbon, low-waste economic development.

This paper studies the planning and development of model eco-cities in Japan and China, using a comparative method to examine their policies and programs, design and development strategies, and technological specifics. It aims to extract some of the characteristics of contemporary Asian urbanism and map its path toward a low-carbon society. The comparison will mainly focus on the data of two model eco-city projects, Tianjin Eco-city in China and Kitakyushu in Japan, and address a few key issues of eco-cities in order to enhance the understanding of Japan's and China's policies and practices including their common, and contrasting, approaches to urban sustainability, the relationship between the building of an eco-city and local economic and cultural development, and the roles played by the governments and the private sector in this effort.

The Rise of Eco-City Movements in Japan and China

Eco-city in Japan was formalized in 1997 in legislation with a financial plan to support it. Twenty-six cities had been designed as "Eco-towns" in this program. In February 2008, the government established a Cabinet-level Panel on Low-Carbon Society to study solutions to deal with global warming and a wide range of related issues. One of the decisions made by the panel was the creation of "Eco-Model Cities." The panel chose model cities in order to promote drastic reductions of greenhouse gas emissions and encourage local communities to promote integrated efforts that incorporate existing knowledge and information into social and economic systems and make good use of local characteristics. Consequently, six cities – Yokohama, Kitakyushu, Toyoma, Obihiro, Shimokawa, and Minamata – were chosen from 82 total applications as the first group of Model-Eco Cities, which was announced at the G8 Summit at Hokkaido in 2008. Both the Eco-Town program and the Model Eco-City initiative address particular issues of Japanese society such as shortage of natural resources and the aging population. The eco-city concept is also seen in Japan as an effective way to revitalize previously environmentally degraded cities, direct national government funding to the most effective areas, and deal with climate change in the face of the reduction of nuclear power as a result of the 2011 Fukushima disaster.

China, on the other hand, is experiencing rapid and large-scale urbanization, and its urban environmental is facing unprecedented challenges under the dramatic growth. The 17th National Congress of Chinese Communist Party (CPC) in 2007 put forward the low-carbon eco-city model as an important part of the overarching agenda of "eco-culture" calling for the building of "a harmonious world characterized by sustained peace and common prosperity." More recently, "urbanization" was highlighted in the 18th National Congress of CPC, when Premier Keqiang Li called for leading the country's mass urbanization toward a sustainable path to create new venues for jobs, consumptions, and investments, to balance mega-cities with small towns, to correct economic disequilibrium between coastal and inland regions, and to improve energy efficiency and air quality. These directives have encouraged local governments to pursue eco-city developments. By 2014, more than 230 cities have responded with initiatives to create eco-cities or low-carbon cities following the standards set by the Ministry of Environmental Protection and the Ministry of Housing and Urban-Rural Development (Ghiglione, 2015).

A comparison of the eco-city movements in Japan and China reveals both common approaches characteristic of eco-city development in Asia as well as fundamental differences in their respective policies and strategies toward urban sustainability. One of fundamental distinctions involves the models of retrofit versus new town development. Retrofitting existing cities appears to be the primary way of building low-carbon cities in Japan. It stands in contrast to China's approach of planning and building numerous eco-cities from scratch due to its explosive urbanization. Another issue to compare is the difference between a top-down approach and a bottom-up one toward the eco-city. Both governments took the lead and played an important role in eco-city development, and the projects were carried through public-private collaboration. Comparisons of the case studies of Kitakyushu and Tianjin Eco-city illuminate the policies, designs, and implementation of eco-city in Japan and China.

Kitakyushu and Tianjin Eco-city

Both Kitakyushu and Tianjin Eco-city have a comprehensive ecological agenda and have established detailed environmental performance indicator system. Both receive substantial governmental support and enjoy extensive international exposure – Kitakyushu was among the first to be included in the Eco-Town program as well as in the Eco-Model City Initiative, and Tianjin Eco-city originated from the inter-governmental collaboration between China and Singapore. Both have developed incrementally for a number of years and seen the result of ecological planning. Tracking the transformation under the eco-city agenda, analyzing their spatial components, and comparing their indicator systems would provide insights into the different paths of sustainable urbanism in the two countries.

Kitakyushu rose as one of the early industrial bases of Japan in the early 20th century, and continued to develop through the post-WWII period. The growing manufacturing power, however, also impacted the city from the other side, making it one of the heavily polluted placed in the country. In the 1960s, the Women's Association in Kitakyushu launched the anti-pollution campaign, which pushed the local government to enact a Pollution Control Ordinance and the private sectors to sign on a series of pollution prevention agreements. The grass-root organizations continued to play an important role in the city's drive for sustainability, particularly after the emergence of Local Agenda 21 in 1996 (Sustainable Cities International, 2012). Despite all the top-down policies and incentives that the city has been readily received, Kitakyushu's pursuit of urban sustainability remains pretty much bottom-up practices and involved different walks of the city.

On the other hand, the Sino-Singapore Tianjin Eco-City (SSTEC) is a brand new town built from scratch under the inter-governmental partnership between China and Singapore. The eco-city occupies a total area of 34.2 square kilometers and will be home to 350,000 residents when completely built in 2020. The choice of the site with its majority being saline-alkali land and wasteland indicates the governments' awareness of ecological challenges and shrinking land resources and determination to tackle these issues. Planned by the government and developed primarily by state-owned companies along with their Singaporean counterparts, Tianjin Eco-city followed a top-down approach although the joint venture is operated like a corporation. The primary economic driver of such project is not incentives for environmental improvement, but rather financial return from land development. Most eco-city projects in China follow this path. They looked to Tianjin as a model for standards and implementation of planning and building an eco-city. They framed their indicators based on Tianjin's EPI system, and many sought international partners for importation of know-how and, more importantly, added brand value.

Environmental Performance Indicators

The Environmental Performance Indicators (EPI) is an essential tool for planning and evaluating the eco-city. The EPI defines a series of threshold or target indexes of social or environmental quality that the city intends to reach within a certain timeframe as the goals of sustainability. The approach to selecting indicators generally falls into two general categories, top-down or bottom-up. The top-down approach means policy makers define the goals and accompanying indicators, and the data collected is usually highly technical and requires experts to interpret. The bottom-up approach is community-based and involves extensive consultation with stakeholders to select appropriate indicators. Kitakyushu and Tianjin Eco-city represent these two different approaches to controlling and measuring the development of eco-city.

Table 1. KPIs of Kitakyushu. Source: City of Kitakyushu, *Kitakyushu Eco-Future City Plan*, 2012.

No.	KPI Area and Detail	Indicative Value	Time Frame
I. Environment			
1	Carbon emission	11.8million ton CO_2 (25% cut based on 15.6 million in 2005)	2025
2	Generation of renewable energy	730,000KW (up from 40,000KW in 2010)	2025
3	Reduction of carbon emission with green Transportation system	2,362 ton CO_2 (29% cut based on 3,315 ton in 2011)	2025
4	No. of strategic international cooperation projects	10 (up from 3 in 2010)	2025
5	No. of international environmental trainees accepted	3,000 in 2021-2025 (up from 2,077 in 2006-2010)	2025
6	Bio-diversity	Zero loss of species in protected area	2025
7	No. of people participating in eco-tours	1 million (up from 100,000 in 2010)	2025
8	Amount of lithium-ion battery recycled	25,000 ton (25% of Japan, up from zero in 2010)	2025
9	Solar panel system recycled	80MW (up from zero in 2010)	2020
10	Household waste generation and recycling rate	450g/household (down from 506g in 2009), 40% recycled (up from 30.4% in 2009)	2025
II. Responses to Aging Society			
11	Citizens who feel the efforts of health promotion have been enhanced	30% (up from 26.7% in 2010)	2025
12	Citizens who feel the efforts of regional medical (home care, etc.) have been enhanced	20% (up from 15.9% in 2010)	2025
13	Proportion of elderly people feeling their own health as "good"	50% (up from 38% in 2010)	2025
14	Employment of elderly people	25% (up from 20% in 2010)	2025
15	Citizen feeling the increase of a network of mutual support	25% (up from 20% in 2010)	2025
16	No. of schools supported by the business community	All elementary and middle schools (up from zero in 2011)	2025
17	Proportion of parents feeling support by people in the region	70% (up from 52.2% in 2010)	2025
III. Others			
18	Support of reconstruction of Great East Japan Earthquake disaster area using the outcome of Kitakyushu smart community	Consultation is being conducted	immediate
19	Total floor area of the data center facility	50,000 m^2 (up from 15,000 m^2 in 2011)	2025
21	No. of contracts of international business projects at Asian Low-Carbon Center of Kitakyushu	A total of 100 by 2025 (only 1 in 2010)	2025
22	Technology and know-how related to water supply and sewage to be exported abroad	6% share of the projected 31 trillion yen business of water treatment	2025

Kitakyushu's indicators system is based on the so-called DPSIR (Driving forces, Pressures, State of the Environment, Impacts, Response) System, a framework for organizing information about the state of environment. It is adopted by the European Environment Agency to assess and manage environmental problems by describing the interactions between society and environment (SCI, 2012). It is composed of the following components:

- Driving forces of environmental change (e.g. industrial production)
- Pressures on the environment (e.g. discharges of waste water)
- State of the environment (e.g. water quality in rivers and lakes)
- Impacts on population, economy, ecosystems (e.g. water unsuitable for drinking)
- Response of the society (e.g. watershed protection)

Kitakyushu city has revised the DPSIR into a more community-driven system by adding new elements that reflect the changes in the environmental systems and making it more relevant for the local conditions of Kitakyushu itself as well as the Asian cities that were included in the Kitakyushu Initiative. The result is a set of indicators reflected in the table 1.

Table 2: KPIs of Tianjin Eco-City. Source: http://www.tianjinecocity.gov.sg

No.	KPI Area and Detail	Indicative Value	Time Frame
I. Natural Environment			
1	Ambient air quality (days meeting National Ambient Air Quality II Standard)	> 310 / Y	Immediate
2	Quality of water bodies	Grade IV of China's national standards	2020
3	Quality of Water from Taps	Potable	Immediate
4	Noise Pollution Levels	Satisfy the stipulated standards	Immediate
5	Carbon Emission Per Unit GDP	< 150 ton/ $1 million	Immediate
6	Net Loss of Natural Wetlands	0	Immediate
II. Man-made Environment			
7	Proportion of Green Buildings	100%	Immediate
8	Native Vegetation Index	70%	Immediate
9	Per Capita Public Green Space	>12 m^2/person	Immediate
III. Life style			
10	Per Capita Daily Water Consumption	<120 L/day	2013
11	Per Capita Daily Domestic Waste Generation	<0.8 kg	2013
12	Proportion of Green Trips	90%	2020
13	Overall Recycling Rate	60%	2013
14	Access to Free Recreational and Sports Amenities	< 500 meter	2013
15	Treatment of hazardous and domestic waste	100%	Immediate
16	Accessibility	100% barrier-free access	Immediate
17	Services Network Coverage	100%	2013
18	Proportion of Affordable Public Housing	>20%	2013
IV. Developing a Dynamic and Efficient Economy			
19	Usage of Renewable Energy	>20%	2020
20	Usage of Water from Non-Traditional Sources	>50%	2020
21	Proportion of R&D Scientists and Engineers in the Eco-city Workforce	> 50 /10,000 workforce	2020
22	Employment-Housing Equilibrium Index (residents employed in the Eco-city)	> 50%	2013

Tianjin Eco-city's Key Performance Indicators System was developed in April 2008 based on the current Chinese national standards and best practices in Singapore. The framework includes 22 quantitative indicators and 4 qualitative indicators, as presented in table 2. The qualitative indicators appear to be general expectation without operational guidelines such as "maintain a safe and healthy ecology through green consumption and low-carbon operations," while the quantitative ones contain concrete criteria. The quantitative KPIs are grouped into four categories: natural environment, man-made environment, life style, and economy.

These Indicators were incorporated into the Kitakyushu Green Frontier Plan. Among other goals is a clear target of 50% CO_2 reduction by 2050 compared to the level in 2005, expecting 40% economic growth in the same period. The plan also calls for the reduction of CO_2 in the entire Asian Region equivalent to 150% of Kitakyushu's own emission. The mid-term goal, aiming for 2030, is to reduce the city's carbon emission by 30% based on the figure in 2005.

Within these KPIs are some standards that represent notable improvement from existing practice, such as preserving wetland, making tap water potable, and demanding all constructions to meet China's Green Building standards. It is also commendable that the eco-city set a concrete carbon density of 150-ton carbon emission per million dollar GDP, and a goal of 90% green transportation. There are, however, some mediocre numbers. For instance, the renewable energy would account for only 20 percent of the total energy consumption by 2020, compared to China's national plan that requires 15 percent for renewable energy by 2015. Another KPI call for 20% of residential development to be subsidized affordable housing, but the number of affordable housing units in Tianjin has been around 50% of the total new housings since 2011.

It is neither simple nor very meaningful to compare the individual indicative values of the two cities' indicators system due to their different stages of economic and social development and the different emphases of eco-city agendas. However, it is illuminative to compare the set of data they chosen to include in their respective evaluation system as they indicate their understanding of the eco-city from their respective social contexts. Kitakyushu's system emphasizes reduction of carbon emission and economy of recyclability. Not only is there a firm target of carbon emission for the city in general, each district and many manufacturers have set a mission of carbon emission (Kitakyushu Green Frontier Plan, 2011). In addition, a subset of the indicators is dedicated to the goals of dealing with issues related to the aging society, which is not only a challenge to Kitakyushu, but one facing Japan in general. The populations in many Japanese cities, including other eco-model cities like Kobe, are declining, with young people moving to the country's few mega-cities (Tokyo and Osaka) for better job opportunities and the elderly left without sufficient care. A major objective of the eco-cities in Japan is to strike a balance between creating dynamic economy, through the development of recycling industries among other strategies, and enhancing social sustainability through redistribution of resources. The fact that the evaluation of social sustainability is based on the survey of degrees of satisfaction among residents also demonstrates that bottom-up force plays an important part in shaping the eco-city agenda.

In contrast, the indicators and means of evaluation characteristic of Tianjin Eco-city's KPI system appears to be more objective and technical, indicating characteristics of a top-down approach. As a brand new city, SSTEC focuses on attracting population and businesses through promoting a higher standard of living environment and unique opportunities. Even though urban population in China is growing dramatically, SSTEC is still facing fierce competition with many other new cities across the nations as well as those established urban centers. Economy assumes a high priority in the eco-city development as the administration shrewdly chose the indicators that could help most in enhancing the eco-city's competitive advantage without committing to some high-expense sustainable items. Some scholars also noted that the real estate sector has a lot of say in the direction of eco-city development. Developers view the concept of eco-city as a selling point and associate them with such values as "luxury" (Springer, 2012). Social equality is marginal in SSTEC's agenda, and it is not surprising the affordable housing accounts for much lower percentage than the average level in the city of Tianjin.

Conclusion

The concept of eco-city is changing the way cities are being built and resulting in new urban landscapes in Asia. It is applied in projects of different scales and in different urban setting such as greenfield projects or retrofit of existing cities. There is no one-size-fits-all formula. Differences in political system, economic conditions, and geographic characters necessitate different approaches to eco-city, as this comparative study reveals.

Japan and China represents two important models of implementing an eco-city. Eco-cities in Japan have a grassroots origin. Organized around national government's legislation and incentives, efforts within Japanese towns and cities are often driven by the local government, industry, and citizens, and involve support of the NGOs. As a result, Japanese eco-cities have a clear focus on citizen involvement and initiatives, as well as strong awareness of recycling and other environmental practices. The "Three R's: Reduce, Reuse, Recycle" is the principal theme for most of Japan's eco-town projects. In contrast, eco-cities in China are characterized by a top-down process. The central government made the policies and created the standards of eco-city, and the local governments and state-owned corporations took charge in implementing the large-scale projects, expecting financial returns from the development of land. Participation takes place amongst political and economic elites but does not involve communities. There seem to be an assumption that a sustainable lifestyle could be built into the city along with the introduction of recent technologies, which often turn out to be a naïve conception.

There are things that these two different models can learn from each other. Japanese cities could benefit from some experience of Chinese counterparts in stimulating economic vitality through the eco-city initiatives. Chinese governments, on the other hand, should investigate the means to bring the communities into this effort as a stakeholder, and enhancing the measures of sustainability with micro-scale interventions. As other scholars noted, Tianjin represents a unique position and possesses many advantages as a demo-project that other cities do not have. For example, government-sponsored low-carbon industries, such as film animation and environmental technologies, are encouraged to relocate to Tianjin eco-city. Other eco-cities will not have the same level of investment or national government support, and their success will depend much more upon how the market perceive a potential environmental premium (Flynn, 2012). In addition, the urban sprawl and massive new town building that have been going on in China for decades will likely slow down in a few years as land resource becomes limited and cities becomes too large to be efficiently manage. Should this be the trend, Japan's approach to retrofit eco-development within the existing cities would represent more valuable experience for Chinese governments that continue to pursue forms of eco-city.

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Sustainable and Green Design in Villages of Rural Southwest China

Adrian Pitts[1] and Yun Gao[1]

[1] Centre for Urban Design, Architecture and Sustainability (CUDAS),
Department of Architecture and 3D Design,
University of Huddersfield, Huddersfield HD1 3DH, UK.
email for correspondence: a.pitts@hud.ac.uk

Abstract: In recent Chinese development the focus for improving sustainable building design has been on urban development. However, a large fraction of the country's population continues to live in rural areas (approximately 600 million); therefore providing and encouraging sustainable development in those areas is important too. This has been recognised in Chinese government initiatives commencing in 2005. Research has been undertaken to record and analyse village development in China's Yunnan Province. Villages vary considerably from cities including ownership of land and buildings, and local cultural influences. The redevelopment and sustainability outcomes also vary. Factors identified as affecting potential success include: village management and the level of enthusiasm of residents to participate in the development process; types of redevelopment encouragement offered (such as support for tourism and craft industries); the degree to which villagers themselves, have knowledge/interest in, sustainable/green design; the ways by which architects and planners are involved in the process; and the level of existing skills/knowledge available. Research has entailed visiting a range of villages and discussing sustainability issues with residents and also with architects and planners. Building surveys have also been performed. Outcomes of the research suggest optimum ways in which sustainable environmental development in villages can occur.

Keywords: China, rural, villages, sustainability, vernacular

Introduction

This paper presents research concerned with sustainable development of rural villages in China. The rapid urbanisation which has taken place in China since the 1990s is now well-known and there have been many investigations and proposals on how to improve the outcomes of that process so as to create greater sustainability. At the same time the number of rural villages has been reducing rapidly with approximately 25% being lost between 2000 and 2010 (ecns.cn, 2016). In the 11th 5-year plan set out in 2005 (www.gov.cn, 2012), the Chinese Government began to introduce changes that recognised the importance of rural areas: the so-called "New Socialist Countryside" (Watts, 2006). These plans defined policies to rebalance urban-rural divergences and included: the development of more modern agriculture industry; the increase of rural incomes; improvements to rural education and skills; improved investment policies; and improved appearance of the countryside along with infrastructure, environmental protection, healthcare and sanitation. Given that more than 600 million people live in rural China, some in very remote locations, policies to create change have taken time to implement. There is currently serious concern that of the 5,000 traditional villages identified for conservation, many are at risk (ecns.cn, 2016). As a result in recent years there has been a renewed urgency to effect change, but there is a risk that in a potentially more frantic rush for such change, some decisions are taken hastily or with incomplete knowledge and understanding. Some serious concerns have been expressed, such as by Lin (2012) that the process is causing “a wholesale shift from regionally specific building types to generic, concrete, brick and tiled buildings. Within this scenario of potentially extreme changes to the social and built landscape, the architect is wholly absent.” It is against this backdrop that the current research has been formulated; it questions whether varied traditional vernacular village dwellings delivered an optimum form of passive or low energy design, and whether their replacement creates a new vernacular, and indeed whether it can be optimized in contemporary village redevelopment.

Background

In cities land ownership is within city and government hands with extensive leasehold development and the development process has been described by many including Chen et al (2011). This has offered much potential in recent decades to leverage finance for major development, and this has also underpinned the remarkable economic performance of the People’s Republic of China. However as with a number of western countries, this does not always result in production of buildings in which environmental sustainability ranks high on the priority list, though some interesting examples do exist (Jiang et al, 2016). Also recognised by some researchers (for instance Pitts and Gao, 2014) has been the method of development which leaves the final stage of completion or of refurbishment to the occupant. Whilst this allows avoidance of complying with certain detailed regulations applying to full construction processes, it also offers potential for residents to improve the sustainability of their dwellings above the basic norms through informed choice and personal investment. Enhancing enthusiasm for sustainable or green outcomes can be supported by capitalising on socio-cultural influences and exchanges of understanding amongst groups. It is also true that there have been significant positive changes at government level leading to greater sustainability potential (energyinnovation.org, 2016).

By contrast, in villages (which are the 5th and lowest level of administrative division in China) much of the land continues to be owned by the villagers, but in general and until recently, they have lacked opportunities to access funds for redevelopment. In any case many original residents are absent having left to work in cities, and since land/property values are much lower than in urban areas there has been less impetus for improvement. Some encouragement can be provided through external support (financial and professional guidance) in a top-down manner though this often happens without a good and detailed knowledge of local circumstances. Villagers themselves can also effect bottom-up change but without some of the necessary expertise, this may also not provide optimum solutions (Gao, 2016). There is need for research in the current critical scenario; a need which this paper aims to aid and so achieve optimised outcomes for village redevelopment. Such redevelopment should respect the beneficial aspects of passive and low energy vernacular design; which is area in which good expertise seems to exist (Sun, 2013). In recent years there has been a renewed ‘push’ for more rapid redevelopment and the authors of this paper perceive an immediate need, and over the next 5 years, not only for research but also for dissemination of information on practical outcomes that can influence development to be more sustainable. Southwest China has been chosen as the focus because of: its often assumed remoteness from development in the East; the representation within the populations of a wide range of China's ethnic groups (half of China's 56 recognised groupings); and also because of the variety of techniques being used to encourage redevelopment. It was also clear that research was required to aid and optimise choices and decisions being made by non-expert stakeholders. Such choices and decision were clearly impacting on effectiveness of construction techniques, resource use, energy demand and the environments to be found inside and around rural dwellings.

The Rural Village

There are perhaps 600,000 administrative villages in China and they come in many shapes and sizes. The 'administrative' village may in fact comprise of several smaller 'natural villages' of which there are more than 2 million. In the more remote and less populated areas of the southwest of they may have a population from several hundred to sometimes several thousands. Natural villages may in contrast have just a few houses and a small number of residents barely in double figures, but most have nominal populations of a few hundred. Natural villages are also often comprised of residents predominantly from a single ethnic group and within which there might exist a clan-like and interlinked familial structure. The detailed explanation of village structure is beyond the scope of this paper but what is clear is that close groupings provide strong social and cultural ties.

The attraction of greater earning potential in major towns and cities has caused a significant exodus of working-age village residents (often male) leaving behind the elderly, women and children. The buildings of de-populated villages are often in a poor state of repair, and though water, electricity and electronic communication systems may well be provided there can be serious deficiencies in other aspects of infrastructure. There are however a number of villages which have retained the majority of their population and which are flourishing. Some of these have succeeded because of the strength of clan leadership or the refocusing of employment around such themes as tourism and traditional crafts. Liao and He (2015) have carried out research into potential outcomes for villages and identified three problematic scenarios which can be summarised as:

- Villages which have become depopulated with many buildings in a state of decay or abandoned with poor basic services, and potential for environmental contamination;
- Villages in which construction has not been well-designed or controlled with consequent poor levels of building and environmental quality;
- Villages in more affluent areas using design features adopted from urban areas such as concrete block construction and large areas of glazing.

In addition to understanding and supporting the sustainable development of villages in rural areas, there is also potential to extend the findings to more urban based villages. These villages often have a specific ethnic bias and may be linked to a particular industry or craft, and may therefore have similar experiences and needs to those in more remote rural areas.

Research Methods

This paper reports findings at a significant stage in the overall project. A variety of research techniques have been employed, including both quantitative and qualitative; it also involves different components ranging ontologically from realism (based around the physical principals that influence dwelling environments) to idealism (based around the complex and changing social and cultural interpretations). Methods therefore also vary from positivism to interpretivism. Evidence used to inform this paper arises from a number of techniques for village investigation: visits to dwellings and interviews with occupants/owners; meetings with architects and planners; collection of visual and measured evidence on construction and environmental performance; discussions with members of Design Institutes involved in the redevelopment processes; and meetings with other researchers. Villages that have been visited are not all individually identified and were often chosen for different reasons and are found around the Province of Yunnan; their locations are spread across several prefectures with a range of ethnic minorities: Kunming (Yi and Yi Sani), Lijiang (Naxi and others), Chuxiong (Zixi), Dali (Bai), Honghe (Hani and Yi), Dehong (Dai and Jingpo), and Xishuangbanna (Dai). Ethical procedures have been adopted in each research interaction.

Mechanisms of Rural Redevelopment

Investigations have been carried out to examine at the local village level what mechanisms are being employed in rural village redevelopment and the reactions of stakeholders. One of the key initiatives discovered has been that which encourages rural villages located in more scenic areas or places with some historical importance, to become tourist developments. Local crafts have also been supported as a means to enhance local economic developments and local infrastructure and services have been improved (see for example Gao et al, 2014).

Since 2015 funding has been made available directly to the inhabitants of some of most vulnerable and important villages; however it seems this has meant the owners of individual dwellings taking decisions to spend funds with less control. This has led in some reported situations to builders from other areas arriving to offer services and constructing buildings with lower standards and less aesthetic appeal, though meeting immediate needs for a modern, watertight and wind-proofed building of large dimensions (often covering almost the total plot area). A further impetus for redevelopment in the southwest quarter of China has come from the recent extensions to the high speed rail network and also the inclusion of even some of the most remote areas in telecommunications networks. Old trading routes are being encouraged linking the Greater Mekong area through established routes to the south (Vietnam/Thailand/Laos/Cambodia) and also through the promotion of the 'Southern Silk Road' in the direction of India via Myanmar (Burma) and Bangladesh.

Village Management

The organisation and management of villages has undergone some major revisions since 2000 and has been linked with removal of agricultural taxes and changes to distribution of centrally controlled income. This has also been encouragement to develop local industries, enterprise activity and income sources. Research carried out by the authors by meeting professionals and village residents has revealed current practices. Externally produced masterplans are now created by architects/planners sometimes with limited connection to the locality. Not all villages have plans at the present time and not all of those plans which do exist may be realizable in practice. A key factor is the relationship with the local village communities acting through a mixture of party officials and the family clan-like social and economic structures. The management of the redevelopment process and the enthusiasm and knowledge of the local inhabitants (in particular their knowledge of green/sustainability issues) plays a very important role in achieving success. From observations made and interviews carried out there is a need to create the correct mix of top-down support and bottom-up participation to achieve appropriate outcomes. Some villages achieve this better than others such as those in which one or more clan groups has particular technical understanding that contributes beneficially to group decision making.

Construction and Materials

The villages of China exhibit a very mixed set of construction techniques and materials usage (stone, timber, concrete, mud bricks, etc). Not only are there regional variations but also differences because of both historic and contemporary restrictions on materials choice. There are also differences superimposed by ethnic grouping and by the intrusions of current styles. The photographs shown in Figures 1 to 4 illustrate the differences between older and modern style dwellings in several villages that were visited in association with the research documented here. Whilst older buildings have a certain 'quaintness' due to local style and materials; occupants interviewed also expressed their dissatisfactions. Research identified that older buildings may have structural problems and allow rain ingress, as well as offering poor control of air flow and temperatures through leaky elements. The openings may not be well-distributed around the buildings and natural light admission can be very poor; washing facilities may also be poorly incorporated. As a result it is not difficult for a resident to be persuaded to opt for a modern building even if it is made from concrete and factory produced windows and roof tiles; and which may overheat and require air conditioning.

Figure 1. Comparison of old and new style dwelling construction in the village of Damoyu, near Kunming.

Figure 2. Comparison of old and new style dwelling construction in the village of Nuohei, Shilin County.

Figure 3. Comparison of old and new style dwelling construction in the villages of remote Xishuangbanna near Mengsoncun (left) and Manguanghang (right).

Figure 4. Comparison of old and new style dwelling construction in the village of Manzhang near Jinghong.

Environmental Performance

In order to establish a baseline of relevant data measurements of internal and external temperatures, humidities and natural lighting levels have been carried out for old and new dwelling types in different villages. Visual surveys of design and construction factors that would impact on environmental performance were also carried out. Space does not permit reporting of the full analysis but the key findings can be summarised as:

- Significant variations in temperatures were observed between old and new dwelling types in the same village and perhaps more interestingly the diurnal cycle of variation showed a different pattern between building styles.
- Orientation of older buildings often determined by Feng Shui or local traditions in relation to topographic features, leading to defined roads patterns; modern buildings may respect the road frontage but have less relationship to environmental needs.
- Both older and newer dwelling are likely to have majority of windows facing in one direction, but windows much larger in size were used for modern designs and with some variety in orientation. Older dwellings often had limited daylight penetration and window location was not well planned with respect to interior features
- Ventilation openings were poorly distributed, particularly in some older dwellings.
- Little or no use of insulation materials exists in modern dwellings; older dwellings also had no insulation materials though some traditional materials may have such benefits.

- Solar shading was often present in older styles but was used inconsistently in modern.
- Though some forms of environmental assessment techniques have begun to appear for rural buildings (Wan and Ng, 2014), these are not yet considered for use in development of the contemporary designs observed and reported here.

Opportunities to Improve Passive Design and Operation

Following from the investigations carried out and observations of design and use of dwellings discussions were held with local Chinese researchers and with local design professionals. This resulted in the authors identifying a need to provide local stakeholders with support mechanisms to optimise design and construction of new dwellings of whatever type in village locations. Relevant start points for consideration are the usual passive design techniques found in many locations and climates of: thermal insulation; use of passive solar gain and linked to daylight; thermal mass; natural ventilation (including night-purge techniques); and evaporative cooling. These have previously been assessed in an exercise evaluating components of buildings that can be modified in local design implementation: orientation; choice of windows; and main construction techniques (Pitts, 2016). This provided a basic sensitivity test. Also considered was the potential to actually introduce change or variations (some options are not possible because of unavailability of technology or materials or technical understanding). Taking all aspects together the authors determined the practical 'potential to improve' and this indicated two prime features which should be provided with better design support/advice for non-expert stakeholders. Table 1 summarises and shows the summarised findings with the key evaluation in the final column. The techniques which are indicated to have the best opportunity in terms of impacts and potential for use to improve environmental conditions are: solar heat gain and daylight admission through choice of windows and orientation; and provision of natural ventilation linked to windows and openings and their orientation/positioning within the dwelling.

Table 1. Impact of selected building elements on dwelling passive design performance (after Pitts, 2016).

Passive Design Feature	Building Element			Potential to use/improve
	Orientation	Windows	Construction	
Restrict thermal heat transfer	low	medium	high	low
Solar gain/natural light	high	high	medium	high
Thermal mass	medium *	medium *	high	low
Natural ventilation	high	high	low	high
Mass + night purge ventilation	medium	high	medium	medium
Direct evaporative cooling	medium	medium	low	medium
Indirect evaporative cooling	low	medium	low	low

* Orientation and windows relate to thermal mass because of control of solar heat ingress.

Conclusions and Recommendations

Rural villages in China represent an enormous opportunity to improve sustainability as part of major redevelopment programmes already taking place. There are multiple influencing factors but there are reasons to be concerned that less optimal outcomes might ensue. The following recommendations and advice are offered:

- Encourage discussion amongst all stakeholders to establish better understandings and prioritisation of opportunities and needs.

- Develop understanding of how villages operate and how best to support them to achieve beneficial environmental design and sustainability
- There is a need for a quick and easy technique to help with energy/environmental design and assessment (with potential for more sophisticated systems in the future).
- In the immediate future there is a need to be realistic about what styles can be used and what changes are possible – design must meet occupant expectations.
- There is future potential to (re)develop traditional skills to meet modern requirements.
- There is a need for more research into how awareness and knowledge about design and construction is gained/used: a research network involving stakeholders is required.

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Transforming Challenges into Opportunities in Social Housing: A Case Study from Italy

Luana Pomponi[1], Eleonora Sablone[2], Laura Rusconi Clerici[3], Lorenzo Consalez[4,5] and Francesco Pomponi[6]

[1] Studio di Architettura Pomponi Associaty – Italy;
[2] Studio Ing. Mario Sablone – Italy;
[3] Tekne Building Engineering, Roma/Milano – Italy;
[4] Consalez Rossi Architetti Associati – Italy;
[5] DASTU (Dipartimento di Architettura e STudi Urbani) Politecnico di Milano – Italy;
[6] Edinburgh Napier University, ISC, f.pomponi@napier.ac.uk

Abstract: Social housing often aims to provide sheltering for people on low incomes or with particular needs. This results in a constraints-dominated context where environmental and social sustainability find little room. Neglecting environmental and social issues, however, risks to further impact those already at the margins of our society, and for whom the social housing was meant to be a life upgrade. Yet, challenges can be transformed into opportunities if intelligent and collaborative planning is utilised. Such a holistic approach has characterised the project discussed in this paper, which has met the design aims whilst placing environmental and social sustainability at its core. Passive strategies have minimised the energy consumption whilst maximising the opportunities that the surrounding natural environment had to offer. Social needs have also been included throughout the various design phases. The result is a plan for a neighbourhood where utterly different users are brought together under the same roof, and social interactions are not just possible but in fact encouraged. Local trade is embedded in the social spaces to incorporate principles of economic sustainability. This case study can be adopted in and adapted to different contexts thus handing back to architectural design the honour and the moral responsibility to produce spaces in which humans as well as nature can thrive.

Keywords: social housing, low energy architecture, passive architecture, social sustainability, local communities.

Introduction and background

Social housing is often primarily seen as providing sheltering to people on low incomes or with particular needs. This frequently results in a constraints-dominated operating context where environmental and social sustainability find little room. This has led to growing concerns with respect to the social and environmental sustainability of housing programmes (Goebel, 2007).

However, low-energy and low-carbon housing is necessary to transition towards a sustainable future (IPCC, 2007, Kellett, 2011) and social housing makes no exception (Moore et al., 2016). This is true across the whole triple bottom line (Brundtland et al., 1987), not just for environmental and social sustainability. Indeed, hosing costs represent – in most countries – a noteworthy proportion of average salaries and therefore changes in the cost of housing inevitably has a noticeable impact on the standards of living (Whitehead, 2007).

Moore et al. (2016) have shown that policy makers often look at social housing primarily through a cost-benefit lens thus undervaluing or overlooking other – equally important –

aspects related to the housing as well as the householders. For instance, social housing developments that are not financially viable can be nonetheless characterised by positive social outcomes as well as improved health of the householders (Moore et al., 2016).

Whilst financial viability is certainly an important aspect to consider in any building project, it is now clear that a building and its intended users cannot be regarded to as two separate clusters any longer. This is because users' behaviour influences – and is influenced by – the building, its energy systems, and the technologies used (Berry et al., 2014). In other words, building users play a crucial, yet "poorly understood and often overlooked role in the built environment" (Janda, 2011 p.15).

Being often handled through a top-down approach, social housing policies and programmes take different forms in different countries and are frequently driven by governments' views and agendas. van Beckhoven and van Kempen (2003) investigated the social effects of urban restructuring in Amsterdam and Utrecht, in the Netherlands. Despite an ambitious intention to replace a "monoculture of low-income households by a thriving neighbourhood, characterised by lively social contacts between different groups and fresh opportunities for local amenities such as shops and schools", in reality the new residents live most of their lives outside the neighbourhood and the interactions with the old residents are sparse (van Beckhoven and van Kempen, 2003 p.854).

Taking into account the intended users and their needs in a social housing programme is a pivotal step towards a project's success, and architectural and social quality have been identified as the two preferential targets to aim for in light of development and regeneration of Italian's neighbourhoods (Boeri et al., 2011a). A further key aspect of social housing development to be taken into account is the area within the city where the development is planned. If in the suburbs, for instant, marginalisation should be carefully evaluated to avoid a fracture from the urban fabric and to enable access to services and facilities of the city (Boeri et al., 2011b).

Such challenges of social housing, however, challenges can also be transformed into opportunities if intelligent planning and collaboration strategies are put in place. Such a holistic approach to social housing has been the case of the project described and discussed in this paper, which has successfully met the design aims whilst also placing environmental and social sustainability at its core. The following sections present in detail the case study and discuss the passive and low-energy solutions implemented along with the elements of social cohesion and local trade. The paper concludes with a reflection on the lessons learned and how the case study presented can be adopted in and adapted to different contexts.

The case study

Teramo is one of the four provinces of Abruzzo, a region in central Italy. Figure 1 shows the geographical location of the province within Italy as well as a zoom in over the area related to the social housing development (shaded red area).

As the right-hand part of the figure shows, the social housing redevelopment happens to be east of the river Vezzola which marks the eastward boundary of the city centre. Therefore, the area of the project is located in the suburbs of Teramo. Furthermore, the morphology of the terrain creates a strong difference in height (+10.6m) between the site and the city, and this has been a challenge for the project team.

Figure 1 - Geographical location of the project

Maximising the social value of the project

It has been precisely the criticality created by the strong difference in height that has driven the project team to transform this challenge into an opportunity. The idea has been to use it as a means to connect the neighbourhood to the broader territorial context, that is the city level on the one side and the river with its path and cycle lanes on the other (Figure 2).

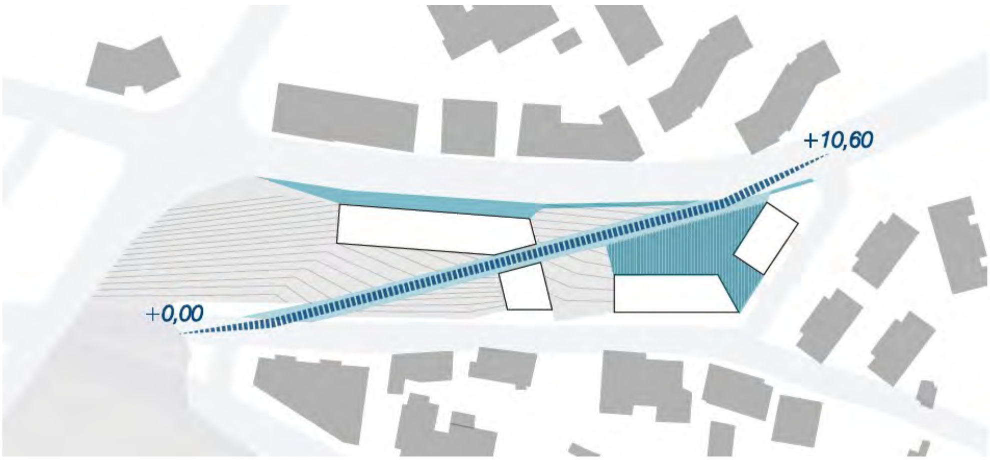

Figure 2 - The path that connects the social housing redevelopment to the wider urban context

Once the pedestrian axis cutting through the neighbourhood has been ideated, it was immediately clear that an opportunity existed to use the social housing redevelopment to impact beneficially also its neighbouring zones so as to become a resource that could avail the whole city. The new path effectively creates a door which connects the social housing neighbourhood to the east part of the city of Teramo developed after the second world war (Figure 3). The two areas, despite being in close proximity, were not easily accessible to one another and therefore social interactions were limited. Furthermore, the pedestrian axis also represents a convenient shortcut to head towards the city centre, thus allowing the wider population of the city to benefit from the redevelopment and its social and green spaces.

Figure 3 - The redevelopment as a new door to and from the city

The new connection with the wider context allowed the design team to reflect on how to maximise the usefulness of the spaces available at the boundary of the social housing neighbourhood. The most notable change to the wider city context has been the one envisaged on Via de Gasperi (Figure 3). This is primarily part of a ring road which pedestrians tend to avoid due to the lack of available spaces for them. However, with the new neighbourhood there is a piazza overlooking Via De Gasperi as well as the west body of the redevelopment placed 5m backward from the street. The clearing created has the shape of a little boulevard or a linear piazza, which allows people to stop by and use the space, either for chilling out or to shop in the businesses trades embedded to serve the city (red areas in Figure 3). The redevelopment has also foreseen trades and services specifically designed for the neighbourhood which are, therefore, embedded in its fabric and but still within easy reach from the main street (orange and yellow areas in Figure 3). This contributes to a strong sense of community whilst also allowing the city and the neighbourhood to mingle harmoniously. Overall, the pedestrian axis represents in fact the backbone of the whole redevelopment to which services, trades, circulation, and structures are all linked.

A further social element taken into account was that of maximising the landscape value of the site, which enables views of both the city centre and the surrounding mountainous areas up to the massif of Gran Sasso. This has been obtained by a creating a wide space between the two main bodies of the redevelopment which are separated by 25m. Additionally, the Piazza at the top level has a large terrace at one of its corners that opens up a view on the river and its surrounding woods.

The last aspect related to social cohesion, diversity and sustainability has been that of providing flexible living spaces that could suit a very diverse range of users, from studio to four-bedroom flats. This has been obtained through simple yet flexible living modules spread across floors and buildings not to cluster specific users' categories all in one place (Figure 4).

Figure 4 - Overview of the different modules to suit the various users of the neighbourhood

Passive and low-energy architectural strategies employed

The site of the redevelopment has been analysed in detail under the idea of a bio-climatic design. Such analysis allowed to understand the specific environmental conditions of the site to inform planning strategies and maximise passive gains and the use of low-energy solutions. Software modelling has been used to identify the areas mostly exposed to direct solar radiation throughout the year by means of shadows cast (Figure 5) and thermographic analysis (Figure 6 – left). This information allowed to understand how to benefit from solar energy as well as which areas would be the most critical during summers and therefore requiring shading to let users occupy and enjoy the outdoor areas.

If on the one hand solar gains are an excellent way to minimise heating demand, on the other wind speed and direction is the 'summer equivalent' to allow for passive cooling. Therefore, thorough wind and computational fluid dynamic analyses have been carried out to understand prevailing wind speeds and directions over the whole year (Figure 6 right and Figure 7).

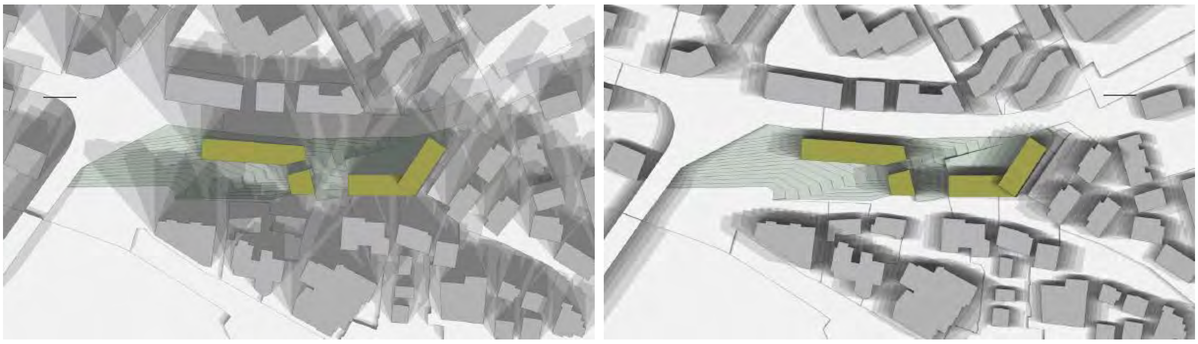

Figure 5 - Shadows cast at 21st Dec (left) and 21st June (right)

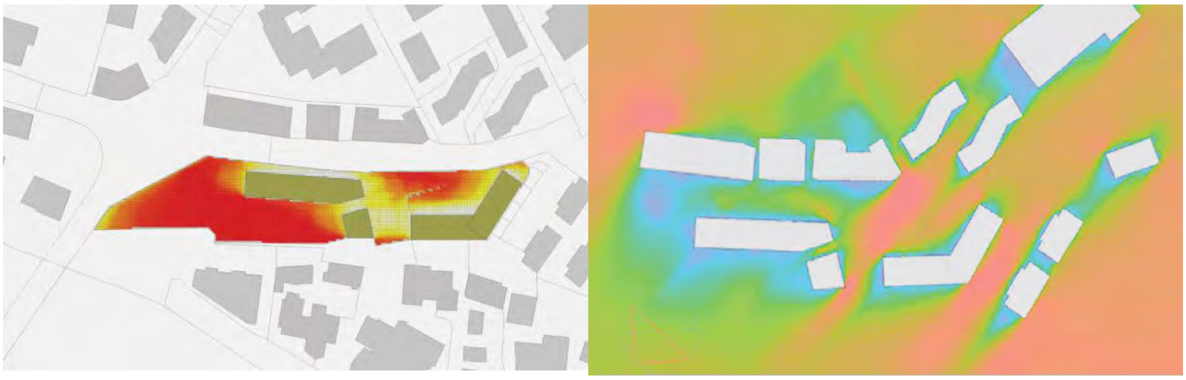

Figure 6 - Thermography (left) and wind direction (right) analyses for the site

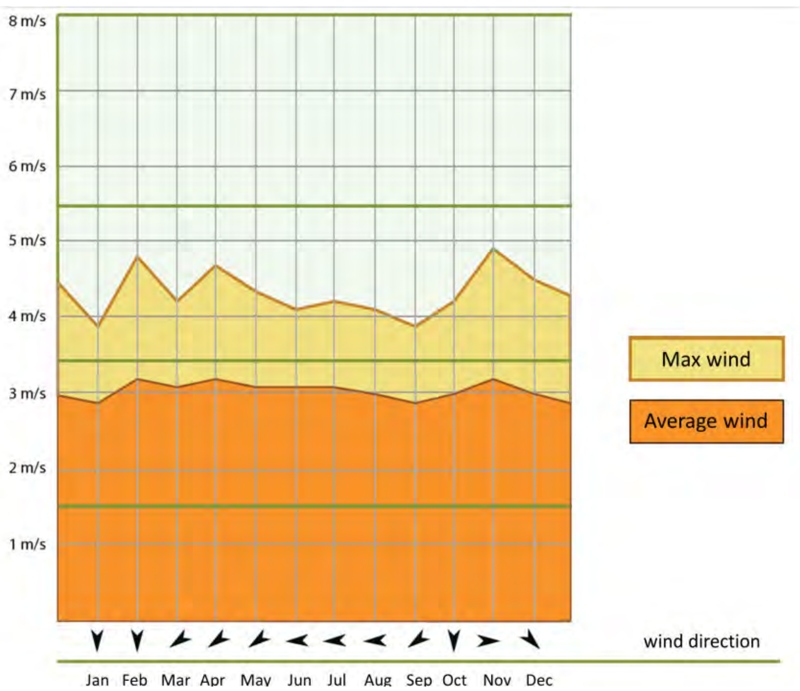

Figure 7 - Analysis of wind speed and direction throughout the year

Understanding the potential the wind had to offer greatly informed both the orientation of the buildings, their heights, and the landscape design to enable corridors for the air to flow and ensure good circulation across the whole redevelopment. In line with principles for good design through natural ventilation (Santamouris and Allard, 1998), cross ventilation between the windward and leeward side of a building has been employed as much as possible. This was followed by the use of cross ventilation on two adjacent walls, single sided ventilation with wing walls as to drive air indoor, and – eventually – single sided ventilation without wing wall as the least favourable option. These were clustered in a scale from Optimal to Scarce and as Figure 8 shows 80% of the living modules were characterised by an Optimal or Very Good score and 95% however had a Good or above score.

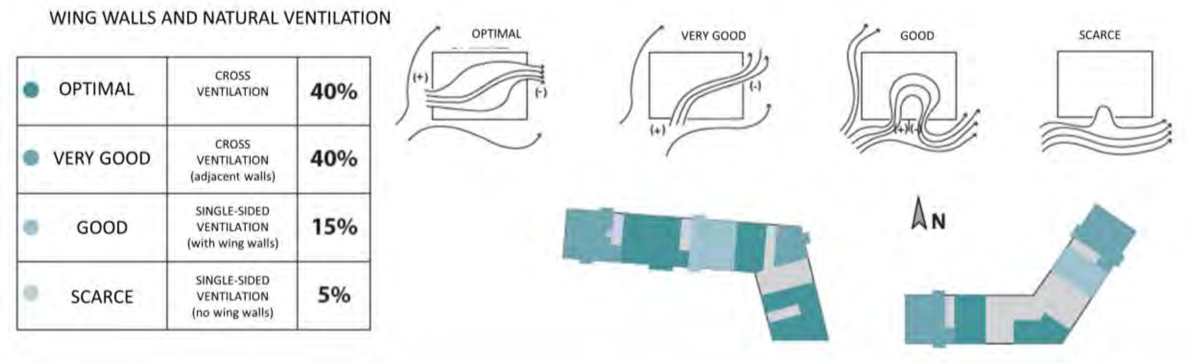

Figure 8 - Natural Ventilation Analysis

Conclusions

This paper has presented the project for the redevelopment of a social housing neighbourhood in the city of Teramo, Italy (Figure 9).

Figure 9 - Side view of the project

The aim of the council was to provide a redevelopment for the neighbourhood that was economically viable. However, the project team went beyond this and has looked at environmental and social sustainability aspects as well. Challenges have been transformed into opportunities through intelligent planning, rigorous analyses, and a collaborative holistic approach to the design of living and social spaces. Passive and low-energy architectural strategies have been used to minimise the energy consumption of the whole development whilst maximising the opportunities that the surrounding natural environment had to offer. Coincidentally, the social needs of the area undergoing redevelopment as well as those of the whole city have been included, enabling a much more vibrant interaction between the neighbourhood and its surrounding areas. Local commercial activities are also embedded throughout the social spaces to give back the built environment to its prime and ultimate users and to incorporate principles of economic sustainability as well.

The project has therefore successfully delivered a plan for a neighbourhood where utterly different building users are brought together under the same roof, and social interactions are not just possible but in fact encouraged. The case study presented in this paper can be adopted in and adapted to different contexts thus handing back to architectural design the honour and the moral responsibility to produce spaces in which humans as well as nature can thrive.

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Design to Thrive

Learning from the chawl. A vernacular urban typology for contemporary communities

Shruti Shiva[1] and Jorge Rodriguez-Alvarez[2]

[1] Architectural Association, London, United Kingdom, Shiva-Ganesh@aaschool.ac.uk
[2]Architectural Association, London, United Kingdom, ETSA Universidade da Coruna, A Coruna, Spain, Alvarez_Jo@aaschool.ac.uk;

Abstract: Mumbai, India's teeming metropolis experiences staggering rates of urbanization, causing an undue exploitation of the built environment. However, this growth is asymptotic to the needs of the city, failing to accommodate large numbers of rural migrants and causing a massive shortage of affordable housing. Although the government has proposed a program of rehabilitative schemes to relocate slum dwellers into high density towers, these buildings lack adequate light and ventilation, and fail to retain the existing ties within migrant communities. The chawls were built by mill owners to house communities of migrant textile workers. It is a dense residential typology characterised by linear blocks, articulated around open corridors and communal courtyards. This paper studies the potential of this typology to inform contemporary passive design, while outlining the role and performance of its key features in providing comfort and creating an enriching social environment. Fieldwork and analytic work were carried out to gain a holistic understanding of both, the environmental performance and cultural value of the chawl. The paper concludes by culling the learning outcomes from this typology, to propose a new outlook for sustainable high density housing through the preservation of urban communities.

Keywords: Mumbai, Chawl, transitional spaces, social housing, density

Introduction

Contemporary India is a landscape of duality. While almost 68% of the population still lives in a rural setup (Urban Agglomerations, 2014) the country is experiencing one of the most intense processes of urbanisation. Indeed, some Indian cities are among the largest and most dynamic cities in the world. Mumbai is a paradigmatic case, the urban fabric of the so called 'maximum city' (Mehta, 2004) is in a perpetual state of flux.

During the British Empire, Mumbai became an important economic node due to its natural harbours. Textile production and maritime trade were the main activities that triggered massive immigration flows from all over the country. This demographic influx caused a housing shortage as the city could not cope with the pace of immigration (Arunachalam, 1978). Mill owners reacted by developing housing estates for their workers. They created a new typology of multi-tenanted shared utilities housing around a communal courtyard, which would later be known as 'chawl' (Shetty et al., 2007).

Despite the decline of the mills from the late 70s (D'Monte, 2002), immigration did not decrease. In order to keep tenant-based housing affordable, the Rent Control Act was introduced (Dighe, 2014), which levied a cap on the amount of rent that landlords could elicit from tenants (Department of housing, 2000). Eventually, this cap discouraged landlords from constructing new chawls while leaving existing structures in a derelict state. The lack of alternatives led to the proliferation of slums, which today, exist as a physical manifestation of systemic failure.

In order to tackle the growing number of illegal settlements, the government launched the Slum Rehabilitative Schemes in 1995 (Singh, 2012). Under this programme, following the consent of 70% of squatter dwellers, the slum is demolished and the inhabitants are relocated in multi-storeyed housing blocks. However, the new buildings not only fail to provide adequate daylight and ventilation conditions but they also fail to create any sense of community or social ties (see figure 1). This research aims to look into potential alternatives to slums and rehabilitated schemes by analysing the social and environmental characteristics of the chawl. The aim is to find inspiration for sustainable social housing in Mumbai.

Figure 1 A rehabilitated scheme and a slum. The environmental quality of the governments' alternative does not get any better than current conditions (Wikimedia Commons, 2016)

The chawl typology

As alluded to in the introduction, chawls (Fig. 2) can be defined as the social housing of colonial times that were built to house migrant mill workers (Adarakar, 2012). Largely concentrated in the south of Mumbai, these housing blocks gained their name from the *marathi* word 'chaal' which meant 'to walk' (Deshpande, 1958). The typical chawl is a U-shaped building, where each wing is composed of a wide open corridor that connects one-room tenements. The wings define a central courtyard that became a centre of activity and community life. Chawls can accommodate nearly 1,200 people per hectare, thus they can be considered a high density social housing typology (Edwards, 1909).

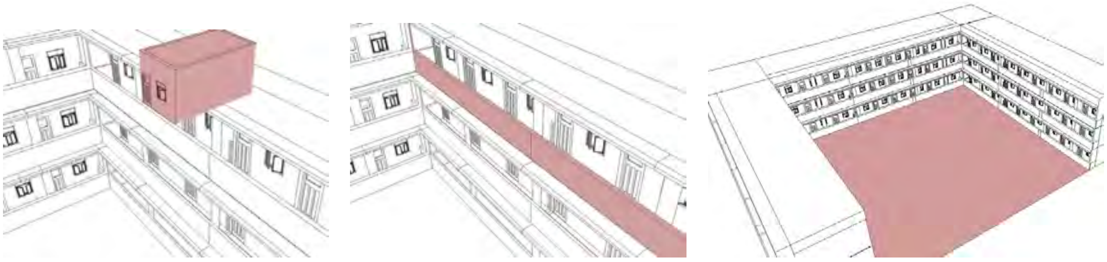


Figure 2 The main parts of the chawl From left to right: The room, the communal courtyard, and the corridor.

Chawls were initially constructed using brick masonry and load bearing wooden framework (Urban, 2013). Later when the construction of chawls moved from private to governmental sector, they were built with a concrete framework and brick masonry to reduce the cost of material and labour (Shetty et al, 2007). A chawl can be characterised by some of its distinct architectural features, namely:

The Room (kholi): A kholi or a unit, consisted of living quarters and a kitchen, measuring around 3 by 3.5m. It can accommodate up to 8 people (Fig.2).

The courtyard (maidan): Most chawls were known for their ample proportioned enclosed courtyards. These courtyards became extremely important social enablers, where festivals, religious functions as well as day-to-day activities like playing cricket, spontaneous discussions and ancillary kitchen activities occur (Fig.2).

Corridors: The characterising feature of a chawl could easily be its long, entwining corridors that serve as key access points for the room inhabitants. Marked at the end of these corridors is an opening, where the main stairwell occurs. This opening is also where common sanitary facilities are located. Due to the compact size of the housing units, corridors serve a unique function of becoming an extension to the living space (Fig.2).

Figure 3 The life in the chawl as depicted by Karandikar (2010): Courtyard, corridor and unit.

Previous studies about the chawl define them as 'vertical villages' in the city (Adarkar, 2012), where courtyards and a series of semi-open spaces, each blurring the lines between private and public, resulted in the creation of a heterogeneous community within a highly urban city (Fig. 3). Karandikar (2010) in her study on two chawls in Mumbai, refers to them as a model for affordable housing. She alludes to the prevalent social diversity, economic and environmental sustainability and the ability to house large densities as important learning outcomes. However, she also warns about the impracticalities of refurbishment, mainly due to their dilapidated state. She rather suggests imbibing the qualities of the chawls into new affordable housing schemes.

Fieldwork

In order to understand the performance and quality of the various space types, a typical chawl was selected to conduct fieldwork. Site visits were carried out in the summer period and during the rainy season. The fieldwork consisted of interviews with the occupants as well as measurements to monitor thermal conditions in courtyards, corridors and dwelling spaces.

The dwellers' perspective

Interviews revealed some key behavioural and social patterns with direct environmental implications:

- Families tend to stay together, thereby resulting in a high density in the small dwelling units, leading to high metabolic gains.

• Women would not give up their private kitchens, which they use intensely. Therefore, cooking is a major source of internal gains.

• The corridor is used as an extension of the dwelling: children use the corridor to study in the afternoon and it used as a communal space during the evenings. The corridor is also used for sleeping purposes in the night if the unit gets uncomfortably warm.

• The courtyard is used not just by children for playing, but also by the adults for communal functions and festivities throughout the year.

Thermal performance of the chawl

Spot measurements were made at the courtyard, the corridor and inside the unit at different times during a summer day and a day in the rainy season. It was observed that air temperature inside the unit was consistently higher than both the outdoor temperature measured at the courtyard and the air temperature in the corridor.

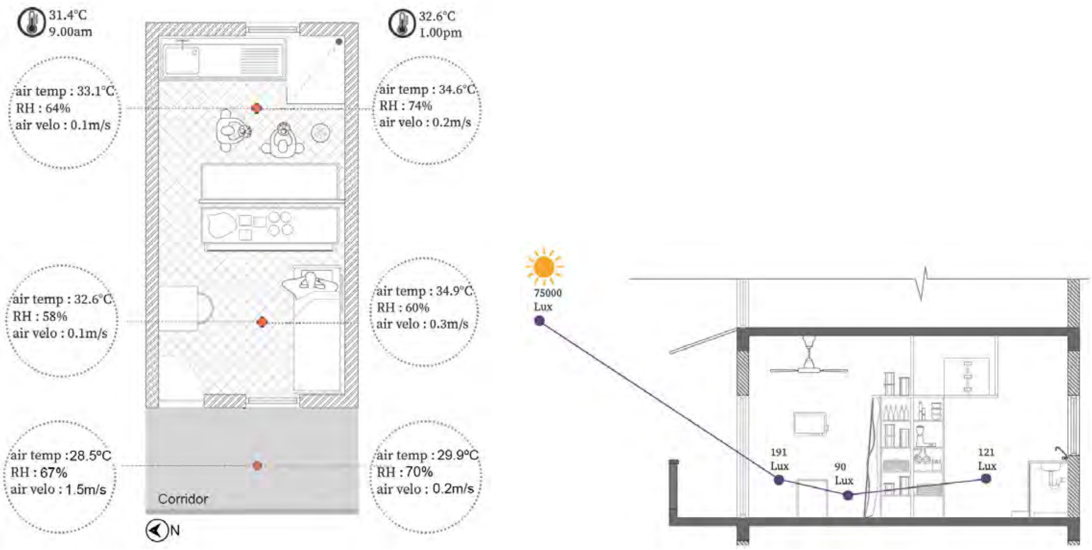


Figure 4 Left:Spot measurements showing temperature, humidity and air movement at 9.00am and 1.00pm. Right: Daylight levels at 1.00pm

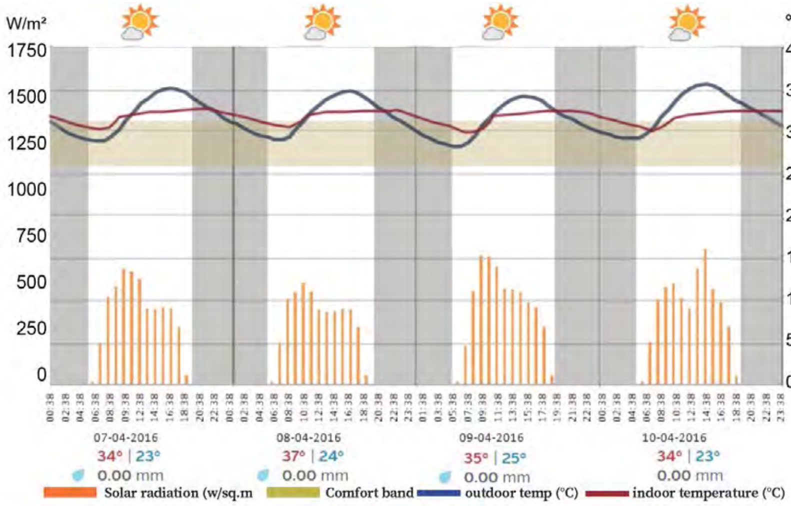


Figure 5 Thermal readings in April (hot season). The temperature in the unit is remains flat and below outdoor temperature during the day

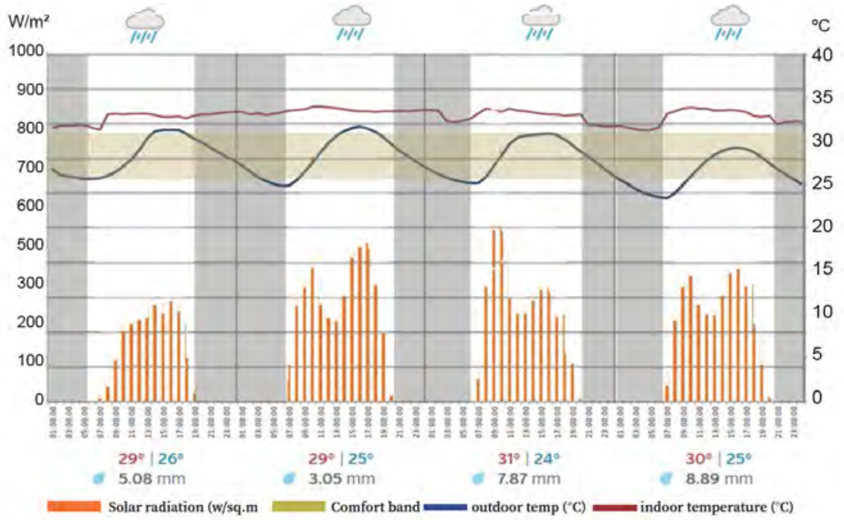


Figure 6 Thermal readings in July (rainy season). The internal temperature is constantly above outdoor and comfort

In addition, a data logger was placed to study the dynamic performance of the chawl over a week in April and a week during the rainy season, in July (Figs 5 and 6). The following observations can be pointed out from the data logger readings:

- The unit is strongly decoupled from the outdoor and while this helps preventing extra gains in the summer, it also prevents heat dissipation during the milder rainy period when the outdoor temperature is lower than the internal one. Moreover, the high thermal inertia and inadequate ventilation prevent efficient dissipation of the internal heat gains. The low window to wall ratio (0.19), has a negative impact in the thermal and visual quality of the unit. The increase of night ventilation, when there is full occupancy, could help reducing the internal temperature in both seasons.
- Occupants' adaptation takes place as they use transitional spaces (i.e. the corridor) for a number of tasks (sleeping, studying, playing...). In addition, occupants tend to keep windows shut during the afternoon when air movement through the space does not lower air temperature. Strong solar gains are observed in the corridor at certain times. The addition of screens or shading devices would provide further adaptive opportunities and allow extended usage of the corridor during the day.

Design research

Fieldwork analysis suggests that ventilation and the symbiotic relationship between the corridor, the courtyard and the dwelling units are critical features in the chawl's environmental performance. The detailed behaviour of these interconnected spaces is further explored through thermodynamic simulations and CFD analysis. A first stage focuses on the courtyard and the outdoor microclimates that are generated. A second stage addresses dwelling units, testing different strategies to improve their thermal performance. Finally, the corridor is thoroughly analysed as a transitional element between the unit and the courtyard.

Analytic work

Courtyard

The aspect ratio and shape of the court were analyzed by measuring the average incident radiation over one typical hot day in existing chawls. It was concluded that the U shaped typology effectively helped reducing radiation on the pavement. This shape was then further tested to define the relationship between aspect ratio, incident radiation and induced wind velocity. It was concluded that greater the aspect ratio, larger the average incident radiation; conversely to increase wind velocity. According to these observations, narrow courtyards offer better conditions. A conceptual courtyard was generated using an aspect ratio and shape derived from the previous study to analyse the impact of surface material (Fig. 8). Various ground cover materials were analysed using Envi-met software and the average surface temperature was calculated and translated into resultant PET values. The results are tabulated in table 1. The results show that grass is a preferred material in lowering ambient temperature thereby helping in reducing the PET.

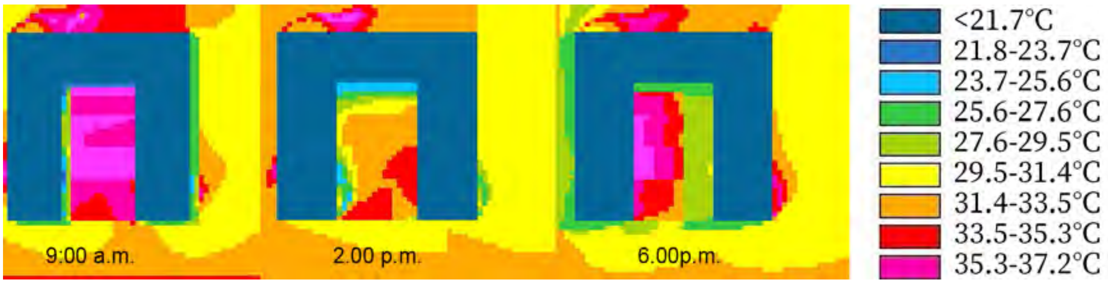


Figure 7 Surface temperature at various times of the day for a conceptual courtyard

Table 1 Surface temperature on the courtyard for different cover materials

	a)Concrete paving	b) Brickbats	c) Paver block	d) Grass
Surface temp (°C)	35.2	38.3	37.2	33.3
PET (°C)	29.1	30.9	30.7	28.6

Unit studies

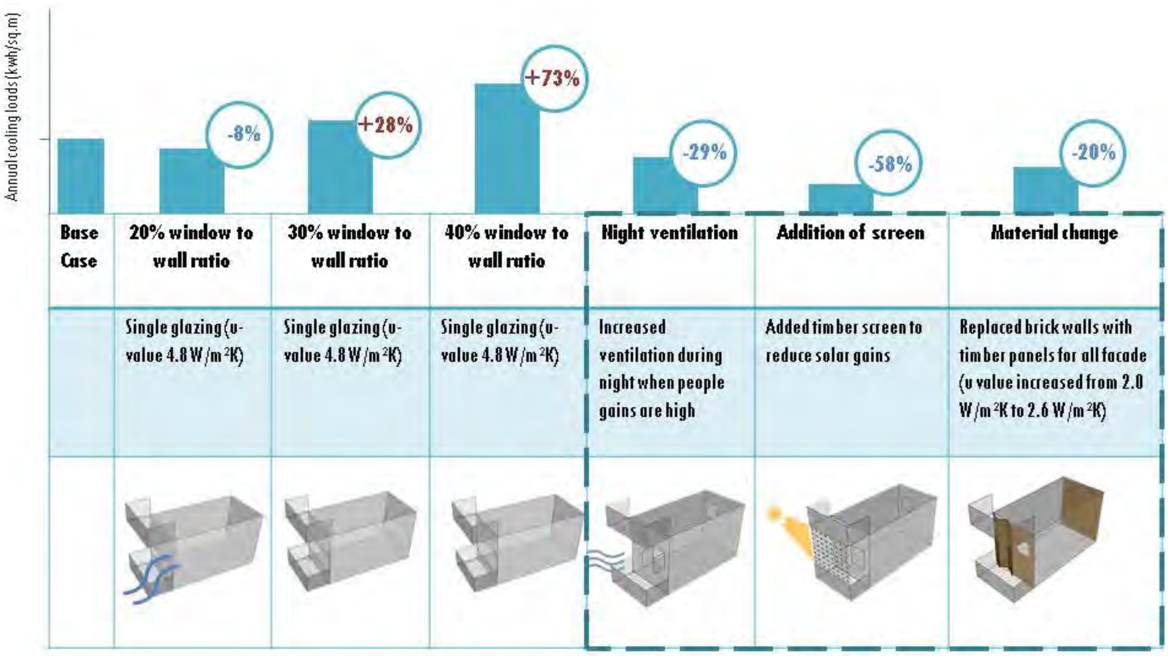
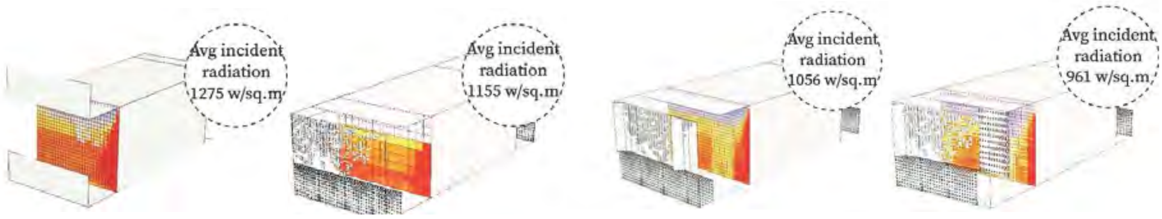


Figure 8 Thermal performance of potential measures in the units

The fieldwork indicated a thermally poor environment in the unit caused by high internal gains, inadequate ventilation and insufficient solar shading. Thermodynamic simulations were performed to test potential improvements. The base case was defined using data from fieldwork (Fig. 4). The effect of various ventilation and radiation scenarios was assessed, using cooling loads as synthetic indicator (Fig. 8). The increase of ventilation by a moderate enlargement of the openings, together with screens to control solar radiation, were the most effective strategies.

Corridor

The corridor was tested for the same factors as the courtyard : reduction in radiation, induction of wind thereby creating comfortable spaces. With the renewed possibility of using the corridor as an extension to the living space, it became necessary to arrive upon a depth that would promote a social culture, would accommodate spill over functions while providing adequate shading. Average incident radiation was calculated using Ladybug over one summer day and the length was gradually increased from the existing a minimum of 1.5m to 3.0m, for all orientations. It was concluded that beyond 2.6m the returns are not significant enough for the extra load on structure and cost it would incur. Hence, a depth of 2.6m was chosen for the corridor. Further, various combinations of shading devices were introduced to increase adaptive opportunity. The lightest shading was applied to the north orientation, where vegetation and movable panels were used. For the south, a combination of movable shutters, movable screens and vegetation was applied. The west and east, receiving the most radiation, were treated with fixed screens and movable shutters. The shading systems were further validated by generating shading masks and tested for daylight to ensure natural light is not obstructed because of the shading, results of which are illustrated in figure 9.



Base case (2.6m overhang) base case+vegetation base case+movable shutters +vegetation Base case+screen+ shutters +vegetation

Figure 9 Radiation analysis of the impact of shading in reducing solar gains

Conclusion

This paper has demonstrated that chawls are a valuable built precedent that can inspire the design of new community schemes. However, current chawls are not optimised for comfort. The research explored the thermal performance in existing chawls and the interaction among their main elements: units, corridors and courtyards. Improvements were devised and tested for all three elements. The courtyards were optimized in materiality, shape, vegetation and form to encourage an array of uses within them. For the unit: the increase of window-to-wall ratio, the reduction of thermal mass and additional shading devices were proven the most effective. As for the corridor, the reduction of solar gains by providing movable vegetated screens has been proposed. PET values of the improved case were generated using ENVIMET and Rayman to validate the various optimizations strategies that were deployed. It can be noted that PET produced lie within the comfort zone (figure 10). Thereby reimagining the chawl as a solution for social sustainable high density housing.

Figure 10 Section through improved proposal showing PET across various spaces; 11am 21st march

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Design to Thrive

A way to reconnect I Cycling Without

Janine Tüchsen[1] and Michel Melenhorst[2]

[1] urbanLab, Faculty of Architecture, University of Applied Sciences Ostwes@alen Lippe, Detmold, Germany, janine.tuechsen@hs-owl.de;
[2] Contextual Design, Faculty of Architecture, University of Applied Sciences Ostwes@alen Lippe, Detmold, Germany, michelmelenhorst@hs-owl.de

Abstract: Thinking about the development of cities, demographic changes and changing lifestyles are the challenges of today. In order to create livable places for everybody, we need to think urban planning in a new way. By making sure, that all parts of a community have access to their surroundings and can participate in shaping the landscape they live in, we create an inclusive, welcoming neighborhood with a unique identity. To highlight the peculiarity of a place we have to focus on tradition and culture taking into account the people using the urban landscape. Currently, some groups have a hard time to understand and contribute the ways of nowadays planning processes. In some places, elderly people can´t be an active part of their environment, out of the loss of mobility. Being outside of a neighborhoods' community reduces their quality of life as well as the diversity of the urban landscape. Through the initiative 'Cycling Without Age' they get a chance to engage to the local society - the neighborhood can reconnect to its stories, its memories and the natural variety, which is necessary to create an exceptional place.

Keywords: urban landscape, quality of life, intergenerational, cycling

Introduction

Urban places reflect their communities and these communities are interacting with their environment. In their interacting, people living in these communities connect to cities, regions and urban landscapes. They shape places in an individual and unique way and are able to identify with their surroundings. Just with an active participation in forming their neighborhood, people will turn urban places into lively, inviting and human spaces, they enjoy to linger.

If a certain part of the community fails in the interaction and the process of city building it means, the form of the city and its public space changes through the loss of diversity and lacks an important component. It will not only exclude this non-participatory group from city life, but also rejects the profit from the potential knowledge, the richness and resource that this group has to offer. Especially people, who cannot deal with the current speed and permanent change of cities nowadays, stop involuntarily, but consequently to be a vital member of the urban society.

In the combination of cities growing rapidly and the phenomenon of aging Western societies one could predict an increasing aging population in many Western cities. Here is no denying it: like it or not, we are all getting older. 'According to the UN World Population Prospects report, the global population of older people is growing at an unprecedented rate. By 2050, for the first time in human history, there will be more over-65s than children under

15. The number of people over 100 will increase by 1,000%. And as by then 70% of the world's population will likely live in cites, this will present huge challenges, and cities will need to adapt.' (The Guardian, 2016).

Especially the generation, who has been living in a certain city the longest and has maybe grown up there, knows its culture, its habits and its traditions best. This calls for greater ideas of obtaining an inclusive society that facilitates all of its inhabitants to actively be engaged in its shaping.

Fortunately there are some promising concepts. One of them is 'Cycling Without Age' that in fact already overcame the stage of a concept. This paper will present that initiative, its importance for people as well as urban city planning and show the poten5al benefit for all involved.

Figure 1. Cycling Without Age

The right to wind in your hair

Facing the demographic change and hectic globalization, the city will go through the challenge of remaining a place for everybody and keeping a unique identity. However, cities grow fast. And cities get older - as do its inhabitants. Apart from the well-known meaning, getting old signifies here as well the gaining of life experience and a shaping of identity, whereby the belonging to a place leads into a growing collection of stories and a deepening of tradition.

But incomprehensibly, history and local tradition are nowadays often considered as nonvaluable looking at the fast taken decisions in the fields of urban planning and architecture: Buildings are being demolished easily; parks, squares and paths rather completely renewed than carefully supplemented. The story of a place looses the battle against the neo-liberal city development, where value is only calculated in terms of direct profit. Newly realized constructions often don´t get older than 50 years and older buildings are easily replaced motivated with greenwashing arguments. If you demolish a building you don't only physically remove it from the cityscape, but also rub out all the stories connected to the place. Personal memory will be forgotten and the ones, who can still remember, are often no longer an active part of the urban environment respectively the community platform of their surrounding neighborhood.

This reason among others connects to the general tendency that the urban city landscape loses its older generation. Under the contemporary circumstances they can't be a part of the city, its speed and its expressions any longer. As a consequence elderly people lose the city space they grew up in. Their lack of mobility coupled with the separation from the local community seriously reduces their quality of life. The initiative 'Cycling Without Age' deals with the question of how to enhance their mobility and how to get them back as daily users of the city landscape. It has emerged from the Danish cycling culture with its tradition for using bicycles as an everyday means of transportation and it rides on a strong wave of voluntarism that is stimulated by a longing for community and purpose. The layout of the city of Copenhagen allows independence to elderly, young and immobile people through a well-developed public transport system and advanced bike lane network. A perfect set-up and a thought through city planning emphasizes projects on a human scale. With that in mind, Ole Kassow started the movement 'Cycling Without Age' in 2012 with the aim to help the elderly get back on their bicycles defying their limited mobility. He started offering free bike rides in a trishaw to the local nursing home residents. Convincing Dorthe Pedersen, who was working as a civil society consultant at the City of Copenhagen by then, of the idea, they bought the first five trishaws and launched 'Cycling Without Age', which has now spread to all corners of Denmark and since 2015 to another 28 countries around the world (Cycling Without Age, 2017).

Intergenerational cycling is an opportunity to get to know urban surroundings from a different angle and to help give our busy city life strong historical roots. It is about cycling through the streets for the sake of it and results in a benefit for all participants: Elderly people profit greatly from having their mobility enhanced and from expanding their social network. The pilots not only get a lot of good exercise, they also get to engage in intergenerational exchanges that bring forth stories of life, which are otherwise easily lost. The passers-by are also an active part in this dialogue: Cycling through a city is way more communicative than driving with a car, because it is easy to get in touch with others nearby. There isn´t a cover, which absorbs the street life and insulates the inmates like in a car or the public transport. Speed and perception appropriate to the surroundings, invite to have a closer look, be aware of and participate in the context.

This urban context is part of a new method of rethinking the city. The public space is transformed into an urban framework for spontaneous and flexible use. With an unobtrusive mindset, public space should adapt and react to different needs, and over that not forget the memories of places and people. 'Cycling Without Age' is an interactive and life-affirming way of slowing down and taking the time to listen. The city space is being enjoyed and a diverse urban landscape is created by people using it. With this in mind, it is a clear benefit for a city to connect to its traditions and to people, who know the city in order to be able to create an identity.

Identity can certainly be formed through the building structure and vegetation - but even more through stories and people. So these human parameters should be relevant for the planning process as existing building structure, topography and climate (among others) already are today.

Figure 2. A Collage of the Lost

An exigency for urban planning hair

The city is a changing place, diverse and unsteady, and working with it, isn´t just a task for city planners and architects, but as well for social workers and all the other parties dealing with and moving through the urban space. Tomáš Valena pleads in his book ’Beziehungen - Über den Ortsbezug in der Architektur’ [Relations - About the locations in architecture] for a sensitive way of integrating the natural, existing surroundings of a place in the process of creating beaer, safer neighborhoods. For him, genius loci - the relation to the context and its characteristic atmosphere - is a major point in working with city landscapes and the quality of life.

Transferring the parameter ’genius loci’ to the population of cities, everybody involved in the planning process learns in a first step about the speciality of a certain place, its culture and ultimately its identity, build up through history and tradition by looking at the locals and studying their way of using the city. In a second step urban planning needs to work within flexible frames, which allow a renewal of forgotten memories and the spreading of lost stories.

Learning from the past and the existing conditions, one need to respect these memories as a valuable gift to create the future. Especially from the people, who have been living in a place for a long time, one can get precious knowledge, which leads into a sustainable, human development.

Strangely enough, this symbiotic effect is hardly recognized in connection of planning a neighborhood. But a social coexistence can just take place in a city, where people know each other, talk to each other and are to a certain degree caring for each other. Creating a sustainable landscape on human behalf, urban planning containing social inclusion is a key factor for the development of a city in eyesight with its inhabitants. Sustainability has to be associated with the social factor of knowing each other. It simply means that we need to improve the amount of time, we spent in direct contact with people shaping the neighborhood: We need to listen carefully.

The city space is a living landscape, always developing and adjusting to its vivid setup. Characterized of its diversity, its changes and its stories, our urban surroundings have to be developed in a way, people can be actively playing a role in the process. This is doubtlessly of importance as the WHO ascertains as following: ’Quality of life is generally admitted to be the result of a fruitful interaction with the environment in its different forms, rather than a mere question of health conditions.’ (WHO, 2001). Quality of life refers for instance to mobility and people’s needs as feeling home and safe at a place, enjoying and belonging to a community. The fulfillment of people’s needs is important for the well-being of everybody and a major precondition for the sustainable development of their urban context.

’Since sustainability implies a balance between environmental, social and economic qualities, policies that seriously decrease an individual’s quality of life can hardly be called sustainable.’ (Marshall, Banister, 2007). A deep knowledge of the provided urban setup of a place combined with an understanding of the people, one is planning for, is therefore, a significant requirement in the development of urban spaces. Enhancing the quality of life is not a simple task, because of the complexity and the difficulty in capturing all the relationships, the dynamics and the features, that exist and are relevant.

But a smart and intelligent urban planning can help improving the quality of life - it is not just a matter of beautiful buildings, safety or clean air, but should as well contain aspects of human satisfaction - whereby accessibility and participation are two of them.

Conclusion

People are making the city to a vivid and lively place - inviting, matchless and welcoming. Not to speak of people of a certain kind, neither a certain age or a certain ethnical background - a diverse collage of people is, what makes an inclusive city to a unique place.

Rethinking urban planning as a discipline, focusing on people of all generations, asking them for help to shape their own places, we will look at the city as a diverse neighborhood – as diverse as the people living there. These places offer opportunities to meet, foster intergenerational relationships and more than that, be inviting around the clock. For the Danish architect and urban planner Jan Gehl, a quality of life in a city can be rated by the appearance of older people and kids. They are representing the ones, who choose actively and out of enthusiasm to stay in the urban landscape - or to leave it. They can decide to go every moment, but if they remain longer, the city remains hospitable to them. Gehl puts it very clear by saying: ’A good city is like a good party. You know it’s working when people stay for much longer than really necessary, because they are enjoying themselves.’ (Gehl, 2010).

Accordingly, the city can strengthen social network by creating vibrant neighborhoods, encouraging relationships and improving the quality of life through creating urban places for everybody and having the patience to listen.

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Figure 1. Wichmann, J. (2015) *Cycling Without Age*
Figure 2. Tüchsen, J. (2017) *A Collage of the Lost*

A case study on Budapest: Lessons on urban resilience

Nikolett Watson-Puskás[1]

[1] Independent Researcher, London, United Kingdom, niki.puskas@gmail.com

Abstract: The city of Budapest was chosen to demonstrate how bottom-up initiatives are able to facilitate participatory design, provide a sense of ownership, giving back the sense of place and the 'right to the city' (Lefebvre, 1996). The post-socialist city has been subject to rapid urban transformations in the past years, most of which are via a top-down approach, presenting challenges which are considered typical due to its socialist history. Its recent policymaking is studied with the impact on the urban fabric and society and how it seems to be unique in some aspects in spite of its historical context, offering lessons to other cities on societal and urban resilience. A number of bottom-up civic initiatives are enumerated in order to analyze how they respond to policymaking fallacies thus leading the way towards resilience. Furthermore, how might they contribute to empowering communities and in the long-term, create an impact what may prospectively support the transition towards a low carbon future.

Keywords: post-socialist city, participatory urbanism, societal resilience, bottom-up initiatives

Introduction

United Nation's New Urban Agenda (NUA) was adopted in Quito, October 2016 (consequently by the UN General Assembly in New York, January 2017) aiming at 'the achievement of the Sustainable Development Goals (SDGs) and targets, including SDG11 of making cities and human settlements inclusive, safe, resilient, and sustainable.' (UN, 2016) Hence providing raison d'etre in a global context for the topic of well-being and placemaking on the agenda of PLEA2017. However, a number of professionals argue the manifesto is not yet followed-up by a clear roadmap providing framework and guidance for implementation. Furthermore, it was discussed how the Multi-Stakeholder Panel including scientists for consultation has been discarded, hence the NUA possibly missing valuable insight. Thus researchers, scientists and professionals have to take leadership in the development of a holistic and interdisciplinary urban science, which must consider the social, ecological and technical infrastructural nexus of urban existence in the quest for urban sustainability, liveable cities, social equity and resilience. (McPhearson et al., 2016)

Global goals can only be reached via local initiatives therefore in practical terms researchers over various locations shall engage in groundwork, bringing together diverse stakeholders via participatory methodologies, for which the local and national governments' collaboration is also needed. To pave the roadmap, the assessment of relevant case studies on a local level is necessary to draw lessons and disseminate for our common benefit. In this paper, the city of Budapest was chosen for such study. Since the fall of the Iron Curtain in 1989, it carries a post-socialist heritage defining the socio-economic and consequently the spatial and urban shaping of this city. Recent years political climate is creating an even more interesting atmosphere, thus offering valuable thoughts on societal resilience and reclaiming the right to the city, as it presents a case on 'what happens when the government does not collaborate or facilitate'.

Setting the Scene

The scope of works, definition of relevant terminology, considerable theories are summarized and Budapest's brief background is given as cornerstones of present paper.

Methodology

The methodology adopted here for data collection and analysis consists of qualitative research elements such as informal interviews with citizens of Budapest and various observations over the past two years, combined with the in-depth review of literature on the city as well as on key topics the research questions entail.

Research questions of this paper fall in the context of SDG11 and encompass the degree of citizens right to the city in placemaking, which is addressed via participatory urbanism and sequentially if they can claim the right for environmental justice. In Budapest particularly, how civic and bottom-up initiatives facilitate these in the evident lack of governmental responsibility and leadership.

Urban Theory

The core discipline to address the above set challenges is urban theory, thus a brief enumeration of relevant contemporary theories is necessary.

Although driven by good intentions, the lack of addressing some of the crucial elements resulted in failed concepts such as new urbanism, which neglected ecological complexities (Rios, 2013) and landscape urbanism, which although addressed the gap between design and ecology, humanity and ecology, recognised the importance of systems thinking and certain elements of resilience: indeterminacy and flexibility, yet lacked practical consideration for cultural systems. These contributed to the emergence of tactical urbanism (and other '-isms'), focusing on micro-environments to achieve more participatory, emancipatory places preserving and celebrating local knowledge, culture and collaboration thus achieving resilient places in a non ego-driven manner but via social ecosystems. (de la Peña, 2015) Similarly, phenomenological placemaking advocates participatory design and community spirit, highlighting sense of place does not come from physical architectural design of a space, rather from social processes. (Aravot, 2002) Consecutively, meaningful urban design accentuates interdisciplinarity and improving quality of life via its three key terminologies: being teleological, catalytic and relevant. (Inam, 2002)

The evolution of theories indicate how urban complexities are increasingly being treated in a more holistic and interdisciplinary manner, recognising attributes such as fluidity, transformative, organic systems where nature forms an integral part. This provides ground for developing resilience, well-being and genuine placemaking.

Resilient Cities

Originally defined by Holling in 1973, resilience is a system's ability 'to absorb change and disturbance without changing its basic structure and function or shifting into a qualitatively different state.' In the sustainability context, the focus is on the ability of this system to 'self-organize and adapt to change'. (Levin 1998; Holling 2001; Walker and Salt 2006). It can also be defined as an essential attribute of social-ecological sustainability. (Walker and Salt 2006). Via a holistic approach, cities are treated as living organisms, every element impacting another, in a fluid and constantly changing complex system. Therefore, resilience is an essential system component.

Citizens are naturally a central component in a city, thus the human-environmental interactions shall be studied with especial emphasis, since humans have a serious impact on the natural environment and the focus of our study: this complex entity called city. They should also be fundamental stakeholders in the shaping of the urban fabric and in the pursuit of well-being and placemaking there shall be discussion on citizen resilience, that is addressing challenges faced along the road of developing these concepts. Ultimately these notions should enhance human life in a sustainable way with respect to the natural world we live in. What happens when these principles are not being recognized, honoured and leading the agenda? Well, the concept of citizen resilience is needed severely.

Budapest Today

The urban landscape of Budapest is mainly characterized by its post-socialist heritage, policymaking of its current illiberal democratic regime and since 1990 a unique, two-tier administrative system shifting some power to the district level.

A post-socialist city carries attributes such as lack of trust, lack of individual initiatives, culture of complaint, a radical separation of 'us' and 'them' as in civil society versus 'the state'. (Polanska, 2008, Grazuleviciute-Vilenskie and Urbonas, 2014) This applies to Budapest too, although an increasing number of successful civic initiatives can be witnessed, implying a growing trust in 'us' yet deepening abyss with 'them'.

Policymaking works in a rigid, hierarchic and bureaucratic, top-down fashion in today's Budapest. There is no open data policy in place, or real citizen-empowering collaborative initiatives, which are recognised valuable instruments for placemaking. (Good examples for these can be found in the UK.) Albeit recent years have seen significant re-shaping of the urban fabric via policymaking, with rather grandiose planning, resulting in rapid urban transformations. The general trend is business as usual with the advent of shiny soulless office and residential buildings claiming to be 'green', going hand in hand with displacement and gentrification and patterns of the post-communist cities: the downtown, popular tourist areas and the neighbourhoods of the elite converging to Western cityscapes, posing harsh contrast to decaying city-parts. (Dingsdale, 1999, Kok and Kovács, 1999, Ladányi, 1997) A classic example is the Corvin project, which aimed to address ghettoization, but just shifted social exclusion geographically. (Keresztély and Scott, 2012)

A number of public spaces were subject to debatable recent remake, in fact one too many to provide an exhaustive enumeration here. Perhaps the first milestone in this 'movement' can be agreed as the 2011 street re-naming campaign of the Fidesz political party upon its return to power. Not physical alteration per se, yet inarguably shaping public space and conception, it affected streets, squares and the city's sole airport as well. The overarching concept of governmental initiatives root back in Soviet occupation: 'artificially emphasizing historical events that were relevant to the Soviet ideology.' (Vaitkuviene, 2010) The same witnessed today packaged into 'national identity', along with using urban design as an instrument to consolidate neo-authoritarianism mostly via falsified or no public procurement like with the reconstruction of Kossuth square, proclaimed as 'democracy square', technically an intimidating ample sterile space. (Akcali and Korkut, 2013) There is a National Football Stadium Development Programme in place, under its umbrella the Groupama Arena was realized and opened in 2014 and the New Puskás Stadium in the pipeline for 2019, argued as one of the World's most expensive stadiums at an estimated total of 618 million euros. Another highlight is the renewal of the Castle District in Buda since the prime minister wishes to relocate there from the Hungarian Parliament. However, the most debated, some call it 'mega project' is the Liget Project aimed at the City Park, sparking fierce dispute over the right for environmental justice. Yet, there is still a scale up: it needs no explanation what it means for any city to enter bidding to host Olympics. Budapest was - up until recently – candidate for the summer games of 2024.

Some of the above examples will be reviewed as they triggered exemplary civic action, thus demonstrating social resilience. Sadly, contemporary Budapest's self-proclaimed technical elite (e.g. mayors, architects) who are so eagerly transform the landscape (Akcali and Korkut, 2013) seem to completely neglect the holistic approach and sustainability manifesto including citizen well-being and the right to the city. Corruption and PR are the driving force instead, when resources are being allocated. (Egedy et al., 2016) This provides somewhat extreme example as more fundamental ideology is at stake since 'public space is constantly eroded by private interests, thus, the democratic character of society is jeopardized.' (Sennett, 2002)

Sustainable city?

Upon the in-depth study of the above cases it becomes crystal clear there is significant growing frustration amongst the citizens of Budapest for multiple reasons – in such case, should we even begin to contemplate if it is a sustainable city? The answer is most likely no.

As part of the European Union, the city has an Integrated Design Strategy, not very ambitious national renewables goals (refer to REN21 2015 report data), situated in a country where there is practically no recognition or incentive to convert to renewables, getting ready to build a new nuclear power plant (Paks 2), whilst many EU neighbours have already dashed miles away in the 'renewables race'.

Yet, we must consider sustainability for it is fundamental in achieving the concepts under discussion in present paper, it must be a driving force in resilience and the question must be answered: What are the inspiring examples in a seemingly bleak landscape then?

The resourceful people of Budapest - Resilient citizens

Buck (2015) reminds us of the significance of framing an issue, thus this paper weaves a positive storyline. Likewise, Castan Broto (2015) discussed how contradictions inspire change, exactly what we witness here. Moreover, a hypothesis that citizen resilience increases exponentially with the governmental strain is considered.

Consecutively, Tarrow (1994) suggests, in a phase of elevated conflict arising from elites setting certain political agendas, collective action could be triggered, which may even result in a systemic change – revolution. Akcali and Korkut (2013) forecasted Budapest as Europe's rebel city in the crusade for cultural and social capital, whilst policymaking creates potential for ongoing protest, which was happening on the streets in April 2017. They also foresaw citizens coming up with innovative ways to claim the right to decide. 'And civil society movements — originating in cities — make clear these win-win opportunities: 'creative place-making', 'localism', 'shared streets', 'universal design' are each about mobilizing local assets to generate liveability and resilience benefits.' (Rowe, 2013)

Ergo we pursue and witness how bottom-up civic initiatives take leadership in the urban realm – a prime testification of what societal resilience is.

Examples of citizen-centred urban design

A highly concise enumeration follows of some notable initiatives in Budapest with the manifesto of the more the people amalgamate and interact, the more they bolster empathy, well-being on a community level (Foster, 2016) contributing to cultivating resilience and promoting SDGs.

A unique phenomenon rooted in Budapest are the 'ruin pubs', the first was Szimplakert in 2002, sprouted all over town since and beyond – in Berlin for example. A classic example of bottom-up temporary urbanism, it became a unique selling point for city branding and tourism. Szimplakert started as a social experiment, a simple venture to finance the promotion of art and culture. They organized cultural events and nowadays also have the Sunday Farmers Market where traditional produce is sold, promoting the slow food movement and teaching about artisan food crafts. In 2013 it won the Viennese Sozial Marie prize for social innovation.

kultúrAktív is an NGO established in 2010, has a number of initiatives under the umbrella of familiarizing and educating citizens on their built environment – the first of its kind - with innovative instruments via gamification. They believe some vulnerable social groups are under-represented, like children, thus having little to no influence on decision-making. One of their projects is Pop-up Pest, aimed at youth, first tested in Budapest during the European Mobility Week in 2012. It is centred at cooperative learning embedded in the target audience's living environment replicated as a giant board game - which we enter and all become equal. Their ultimate goal is empowering citizen engagement in urban development, teaching contemporary urban concepts such as community gardening and public art for example. (Tóth and Poplin, 2013)

Instances of community gardening are founded by KÉK (Contemporary Architecture Centre), not only promoting urban cultivation (i.e. sustainable food production) and improving green infrastructure, but allowing city children to reconnect with nature and teach them skills bridging the gap of having no access to a garden. The initiative is not only about co-working and gardening, but includes meals together, community music jams, group yoga sessions and there was also a midnight painting activity for a new site. The concept of 'planetary gardening' is relevant here, emphasizing the important element of human liability to care through the allegory of nurturing the garden – a notion here scaled up to a planetary level, thus becoming a symbol of more complexity. (Buck, 2015)

Furthermore, smart landscapes must emphasize that technology alone is not a sufficient tool for sustainable agendas. (Buck, 2015) At the heart of the above initiatives shaping the urban environment is the promotion of old-fashioned physical human connections, which are essential for citizen well-being as well as for the facilitation of genuine placemaking. It is crucial in the digital age, which significantly shifted the realm for socializing. Future generations should be raised to understand what physical connections mean, being part of a community and living in symbiosis with nature – which implies knowing nature via first-hand experience.

Continuing with the challenge of sharp contrast between civic and governmental activity, an example is the start of the migrant crisis in 2015. Budapest was not prepared and Keleti Railway Station spontaneously became 'camping site' for the Syrian refugees. The government ignored the issue, but a civic initiative quickly emerged through a Facebook group: Migration Aid had thousands of people joining the cause of giving humanitarian help over just a few days. They spread to a network of five additional cities in Hungary, organized chaos into a system, collected and distributed food and essentials, even arranged a spontaneous screening of Tom and Jerry for refugee children: a temporary community theatre, offering a valuable lesson on equality, diversity and what it means to be human.

The controversial governmental Liget Project also triggered civic action via forming the 'Ligetvédők' group who advocate for participatory democracy and against the playing of policymaking loopholes to redesign space technically reducing green surfaces. They erected tents and maintain ongoing protest since March 2016, yet another example of temporary urbanism, with their two constant camping sites marked on GoogleMaps. Along with further development projects such as the Dagály lido, József Nádor Square, Római-part it prompted NGO-s and some professionals to unite and publish a manifesto, backed up by Greenpeace Hungary to advocate the protection and preservation of urban green surfaces. A demonstration of reclaiming the right to the city, citizens and authentic professionals demand environmental justice – so far falling on deaf ears, yet persisting.

Recently the tension also peaked with the Olympics 2024 candidacy. Momentum Movement started the 'Nolympics' initiative (January 2017) seemingly from nowhere and easily over-achieving the signature target to call for a referendum. In the end, people of Budapest did not get their right to decide, though the city stepped down from candidacy. Then the case of Central European University gave momentum and changed the dynamics in April 2017, with ongoing protest on the streets, some people used orange watercolour to mark the Fidesz rule on public buildings over liberal democracy, a symbolic temporary alteration of the city fabric.

The urban fabric is very adaptive, flexible, a multifaceted symbol, thus can be played with. An ordinary street can be temporarily transformed into something entirely different with added value, like the 'words alley' (Art Moments Festival, 2015), where every pedestrian could write their favourite quote on the pavement with coloured chalks – a simple concept challenging everyday perceptions, providing platform to share something meaningful with others. Similarly, there are 'book-stops' in Budapest, open libraries based on community trust: give and take, promoting equal rights for access to knowledge and culture.

Ascertainment and recommendations

It is every government's and professional's fundamental duty to (re)present socially and ecologically responsible leadership. It is clear from scientific literature that the city is a living entity, constantly evolving and flexible fabric woven of many intertwined layers, thus a merely technical, rigid monodisciplinary architectural approach will not suffice. An equally elastic professional approach must be adopted, designers cannot claim total authority, instead should facilitate open-ended design, urging community participation in the shaping of spaces as they belong to these spaces and vice versa, the space belongs to them. (Dhar and Khirfan, 2016, Tardiveau and Mallo, 2014, de la Peña, 2015)

The main barrier against the demanded change in Budapest is bureaucracy backed-up with rigid ancient infrastructure (including both hard and soft elements). There is an increasing global demand and pressure for change. Some city mayors realize this and choose to lead change, for example Enrique Peñalosa former mayor of Bogotá. In the lack of such public leadership, the activism of Ligetvédők and Momentum Movement are good examples of challenging the status quo and initiating grassroots movements amongst the citizens of Budapest and Hungary, bringing together the community for important causes.

Leaders should realize the most effective instruments for resilience and liveability scale in multiple dimensions, thus granting numerous benefits, some demonstrated above like local food production, community workout, open access to knowledge. Furthermore, heat island effect mitigation, water- and even crisis management. (Rowe, 2013) Growing research proves and quantifies the benefits of nature on human well-being and the resilience of places (see journals e.g. International Journal of Environmental Research and Public Health, BMC Public Health, Landscape Ecology), yet there is no equal evidence of nature-based solutions becoming a fundamental aspect in planning and redesign projects – consequently these cannot be referred to as development or revitalization projects and definitely not as sustainable or resilient. A paradigm shift is needed, authentic attitude in wanting to create meaningful urban design. Until we reach that, present case study demonstrated how in the seemingly complete lack of socio-ecological safeguarding from the top-down, local communities and civic initiatives step up and demand the collective right to a healthy city! They respond to policymaking fallacies, thus empowering communities, creating impact, which may contribute to the transition to a low carbon future, converging to environmental justice – prospect for a beautiful chain reaction.

Citizen resilience is fundamental for authentic sustainable urban development, yet not enough – dialogue is needed, it is time for 'the top' to listen to the people, to change the narrative. This is not a story about power, it is about empowering, harnessing scientific wisdom, bettering ourselves and our environments for everyone's benefit. Otherwise the risk of scepticism and disenchantment of 'experts' and policymakers persist. After all, 'the city itself is a commons – a shared resource' generating goods for human flourishing. Citizens should be central actors influencing its management and governance. (Foster, 2016) Lastly, this paper cannot emphasize enough the fundamental truth of Mancebo's words (2015): 'Inherent to urban resilience is an integrated, holistic understanding of the connectivity and interdependence of the physical, social, environmental and cultural assets and systems of a city...Thus, a sustainable city should result from the confrontation—or the synergy—of choices made by multiple actors, each acting for its own concern.'

Closing remarks

The above recommendations are for all professionals in order to implement authentic placemaking in line with SDG11. This paper argues for citizen-centred design and the utmost importance of granting environmental justice to achieve well-being and meaningful places. Existing good examples must be considered, including traditional societies as they 'represent thousands of natural experiments in how to construct a human society. They have come up with thousands of solutions to human problems, solutions different from those adopted by our own WEIRD [Western, Educated, Industrialized, Rich and Democratic] modern societies.' (Diamond, 2012)

Following the narrative and values respected in this paper, this research will be taken further in a regional comparative action research. Participatory methodologies will be implemented in various case studies to further contribute to the scientific community in paving the way to sustainable liveable urban environments.

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Parametric Optimization of Solar Hot Water Systems for Different Building Types under Hot Climate

Kheira Tabet Aoul[1], Ahmed Hasan[2] and Hassan Riaz[3]

Architectural Engineering Department, College of Engineering, United Arab Emirates University, Al Ain, UAE, [1]kheira.anissa@uaeu.ac.ae, [2]Ahmed.Hassan@uaeu.ac.ae, [3]hassanuaeu59@uaeu.ac.ae

Abstract: Building integrated solar thermal systems are considered an attractive alternative to traditional heating systems for water heating applications. They yield a high potential to efficiently and cost effectively meet a large portion of hot water demand in different building types. However, their performance to great extent depends on the climatic conditions, building water heating requirements and the optimal design and sizing of collectors. The present research attempts to identify a unified parameter for solar thermal sizing for various building types based on their hot water demand under a hot climate. The building types include residential, hospitals, schools, offices and industry. The analysis is conducted numerically through a conjugate heat transfer model executed through TRNSYS platform. The parameters investigated include the collector tilt angle (0° ≤ φ ≤ 90°), azimuth angle (-90° ≤ β ≤ 90°), collector inlet temperature and collector inlet water flow rate. Eventually a unified design parameter of collector aperture area required per unit footprint area for each building type is determined. The unique parameter will help architects in optimal sizing of the collector for specific building types under a hot climate, taken as the climate of Abu Dhabi, United Arab Emirates.

Keywords: Solar water heating systems, building types, parametric optimization, TRNSYS software

Introduction

Bridging the gap between energy supply and demand is and will remain the major challenge of the 21st century. The total world energy consumption has increased two folds reaching up to 13699 Mtoe (million tons of oil equivalent) from 1971 to 2014 (International Energy Agency, 2016). Along this trend, the average installed energy capacity in the Gulf Cooperation Council (GCC) countries was 1149 Watt per person in 2005, which is much higher than the world average (297 W per person) or the European Union (700 W/person), but less than USA (1460 W/person). The GCC countries needed to increase their electrical capacity by 60,000 MW, which represents 80% of the 2011 installed capacity, to meet demand in 2015, making them one of the highest energy consumers per capita in the world (Alnaser and Alnaser, 2011). The United Arab Emirates (UAE) consumed 40740 GWh per capita in 2015 in all sectors collectively (DEWA, 2015), resulting in per capita carbon emissions two times higher than the developed countries (Kazim, 2007).

The energy used in the building sector varies among countries and ranges for example from 30% in the US to over 70% in the Gulf Countries (IEA, 2016; EPCE, 2010; DEWA, 2015; Kazim, 2007). Out of the total energy consumed in buildings, space and water heating needs can be as high as 81% in cold climates (U.S. Energy information administration, 2015) and 30 % in hot climates (Kempener et al, 2015).

In the UAE cooling and domestic hot water needs account for 55% of the energy used in the building sector (Radhi, 2009; Global solar thermal energy council, 2010). The abundant solar radiation in the UAE renders the provision of solar hot water, in particular, an attractive, efficient and economical option to supply housing, commercial and industrial building occupants' needs (Islam et al, 2009; Ghaith and Abusitta, 2014).

The optimum performance of Solar Hot Water Systems (SWHS) depends on its design parameters and the climatic conditions. There are very few studies conducted under the extremely hot climate of the UAE. The existing literature reports on optimum performance considering the right selection of the orientation and tilt angle (Yakup and Malik, 2001, Qiu and Riffat, 2003). Optimal tilt angles for few places has been reported as $\Phi = \varphi + 3.5$ for Egypt (El-Kassaby, 1988), $\Phi = \varphi + (4 \text{ to } -10)$ for China (Tang and Wu, 2004), $\Phi = \varphi + (19 \text{ to } -34)$ for Izmir, Turkey (Ulgen, 2006) and $\Phi = 24°$ for Abu Dhabi at south facing direction (Jafarkazemi and Saadabadi, 2013, Khalil and Alnajjar, 1995).

However, an optimisation of all the influential SWHS design parameters in relation to different building types and their corresponding hot water demand has not been assessed. Hence, the current study attempts to comprehensively cover the unique relationship between collector parameters to hot water demand in different building types to optimize collector performance under a hot climate, in this case, Abu Dhabi, United Arab Emirates (UAE)

Methodology

Simulations were carried out to assess the contribution and effectiveness of SWHS in meeting specific hot water demands in housing, hospitals, schools, offices and industry under the UAE hot climate. The objective was to determine the optimal parameters of flat plate solar collector (of surface area $2m^2$), inclination angle, azimuth angle, and collector inlet water flow rate. A transient thermal model was developed using TRNSYS software (TRNSYS, 2004), integrating the solar thermal collector and auxiliary heating source to provide hot water demand, meeting building occupants' needs in the different building types considered. Eventually, a ratio design parameter of collector aperture area to building area was determined for each of the studied building types.

Results and Discussion

Simulations were conducted employing a typical means year (TMY-2) weather data for Abu Dhabi. Parametric influence of collector inclination angle, azimuth angle, collector inlet water flow rate and collector inlet temperature were determined.

Collector Tilt angle

The performance of solar collector depends to great extent on their inclination angle (Shariah et al, 2002; Moghadam et al, 2011). Designers generally locate collectors on the building roof (pitched or flat) or on the façade (vertical wall). The same is simulated by varying monthly collector tilt angle (Φ) from 0° (representing flat roof) to 90° (representing south facing façade) with an increment of 5°. The average thermal gain (Q_c) is plotted against tilt angle (Φ) in Figure 1 to determine the optimal (Φ) for each month. The thermal gain (Q_c) of January (winter) is 1.95kWh/m^{2}at the tilt angle of 0° which kept increasing to reach at 3.25 kWh/m^{2}at the tilt angle of 50° (pitched roof). Beyond 50°, it gradually dropped to reach 2.2kWh/m^{2}at the tilt angle of 90° corresponding to its potential location on a vertical wall such as facades (Figure 1).

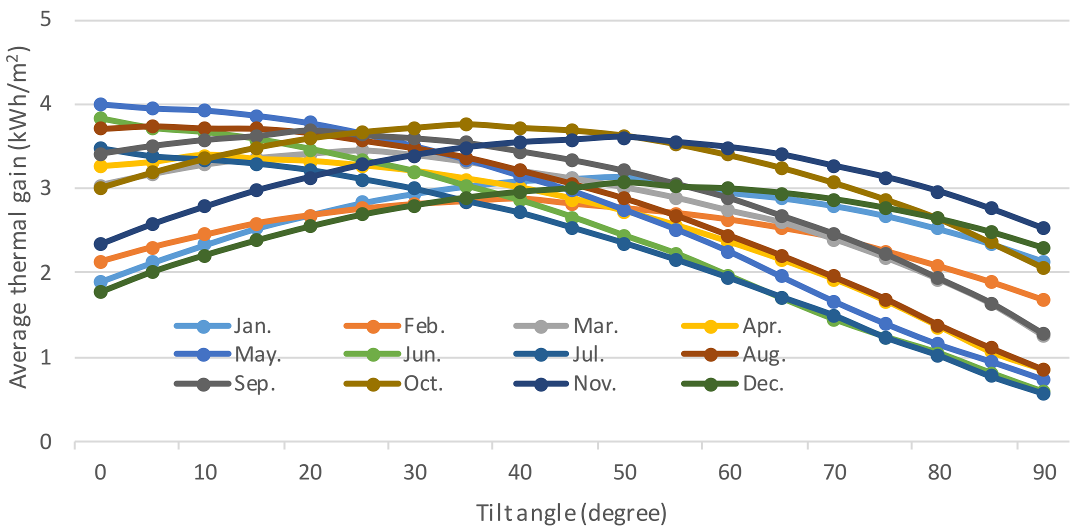

Figure 1: Monthly average thermal energy production of solar collector at various tilt angles

Hence, the 50° is the optimal pitch angle for south facing collector in January for Abu Dhabi. Similarly, for summer months i.e. May, the average Q_c was 4.11 kWh/m^{2}at the tilt angle of 0° which kept decreasing with an increasing angle to reach 0.75 kWh/m^2 at 90°, suggesting that 0° is the optimal collector tilt angle in May. Similarly, the optimal tilt angles for each month were determined based on maximal Q_c (Table 1).

Table 1. Optimum monthly collector tilt angles for enhanced thermal energy gain

Month	**Φ_{opt}**	**Thermal gain (Q_c)**
Jan	50	3.23
Feb	40	2.97
Mar	25	3.58
Apr	10	3.59
May	0	4.11
Jun	0	3.93
Jul	0	3.57
Aug	5	3.87
Sep	20	3.81
Oct	35	3.86
Nov	50	3.72
Dec	50	3.18
Average	23.75	3.62

To determine the yearly optimal fixed pitch angle, the collector slope was varied 12° above and below the average latitude of the place (24°) thus ranging from 12° to 36°. The maximum Q_c of 1207.47 kWh/m^2 was obtained at 24° (Figure 2) represented by latitude of the place thus being in agreement with previous findings (Islam et al, 2009). Further, knowing that rooftops are not always available for optimum solar water heaters layout, the performance of collectors installed at the optimum angle (24°) is compared to a 0° and 90° incline, corresponding respectively to a flat roof and vertical wall and the collector area required per building area is compared for the different building types (Figure 3).

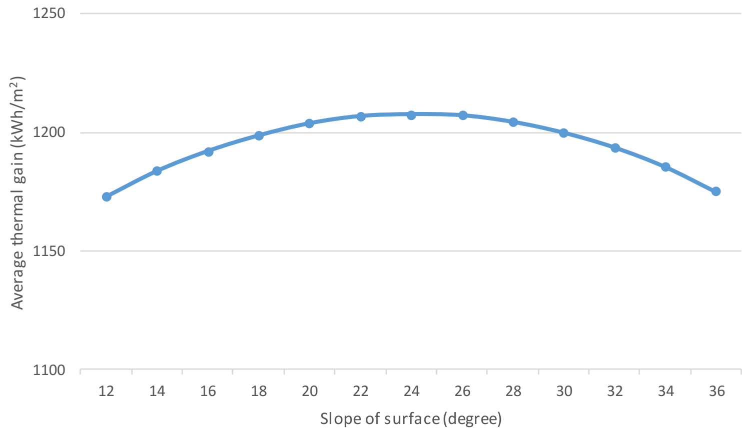

Figure 2: Impact of the off-latitude tilt angle on the thermal energy production of solar collector

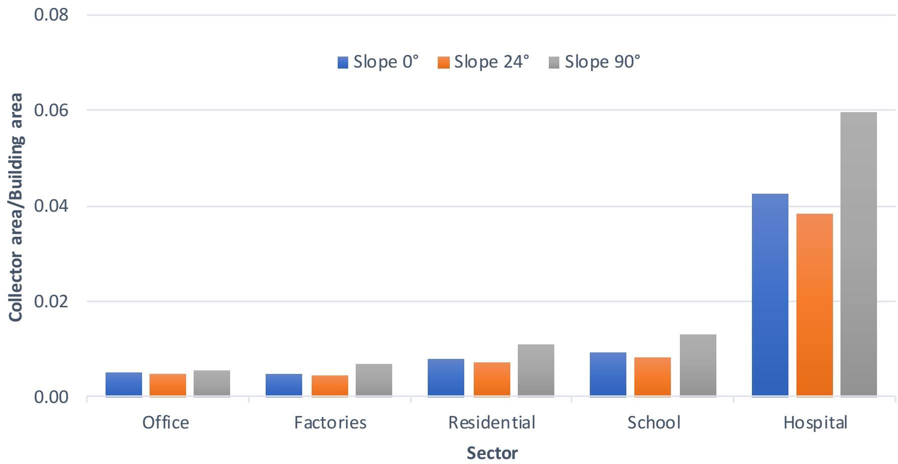

Figure 3: Ratio of collector area required for unit building area at collector tilt angles of 0°, 24° and 90°

The results show that the wall-mounted systems always required higher collector area per building area thus representing the least energy performance. The sloped roof and flat roof integrated thermal collector's performance is comparable due to very low latitude at the site. Comparing building types, the Hospital buildings required highest collector area per building area mainly due to higher occupants' load. The building type characteristics for fundamental parameters of the building and solar collector are presented in Table 2 to determine the collector area required per building area for the different building types considered.

The observed trend depicts that for south facing roof the value of Q_c is peaked at the azimuth angle (β) of 0° due to collector being installed in the northern hemisphere and decreases with an increase in β . For east and west facing maximum gain was achieved at 90° and -90° respectively and it also decreases with the change in orientation. Thus optimal β is 0°, -90, and 90° for the south, west, and east facing roof respectively (Levent Bas, 2010). In comparison, Q_c of the collector installed at south facing pitched roof is 30 % and 22 % higher than west and east facing pitched roof correspondingly. Variation in thermal gain by changing the azimuth angle is attributed to the sun's position as shown in Figure 4.

Table 2: Solar collector area required to meet hot water demand for various building types

Parameters	Residential	Hospital	School	Office	Factories
Building Size (square meter)	1000	1000	1000	1000	1000
Floor area allowance per occupant (square meter per person) (International Building Code, 2009)	19	Patient room: 11 Other spaces:22	Classroom: 2 Vocational spaces: 5	9	9
Occupant load (Number of people)	53	68	350	111	111
Hot water demand (gallon per person per day) (ASHRAE Handbook, 2011,The engineering toolbox 2016)	35	35	3	5	10
Total hot water demand per building use (gallon per day)	1855	2380	1050	555	1110
water temperature Tr (°C) (The engineering toolbox 2016)	45	65	45	45	45
Solar heated water per m^2 of the collector (gallon per square meter)	261	248	505	113	257
No of collector required	7	20	4	5	4
Collector to building area ratio	0.0071	0.0383	0.0083	0.0049	0.0043

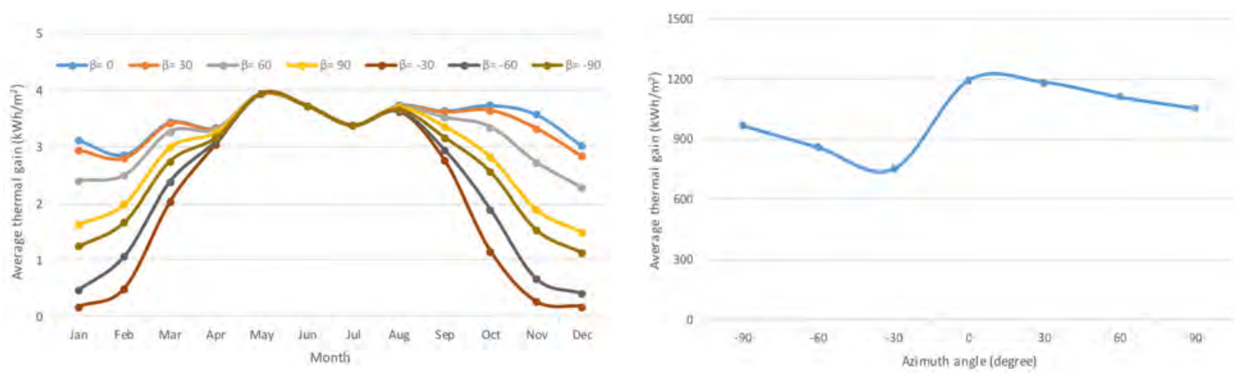

Figure 4: Monthly (left) and Yearly (right) average energy contribution from solar collector with varying azimuth angle

Inlet flow rate

Daily water consumption for each building is calculated from code requirements to size the collector storage tank and is kept fixed for the whole year. Since the thermal collector only recovers energy during the daytime, the varying daylight intensity and hours affect the thermal energy received by the collector. The variable energy available at the absorber needs demands variable water flow rate for optimal energy recovery. The optimal water flow rate inlet to the collector thus needs to be determined for different months. The total daily water demand is circulated through the collector during daytime (represented by daylight hours) at various flow rates to determine optimal flow rate for each month and building sectors. The summer season (May and June) had the highest number of daylight hours with an average of 13 hours, while the winter season, (January and December) had the lowest daylight hours with an average of 10 hours in Abu Dhabi (El Chaar and Lamont, 2010). Inlet water flow rate was higher in winter months and lower in summer months for all building types shown in Figure 5. Moreover, the hospitals required the highest while offices required the lowest water flow rate (gallon/hour).

Inlet temperature

The influenced of ambient temperature on the collector inlet water temperate is incorporated in the model by assuming the inlet water at slightly higher temperature than the ambient due to heat retention in water. The collector inlet temperature is assumed to be 3 – 4 above the average daytime ambient temperature ($T_{avg\text{-}amb\text{-}day}$). The highest value of $T_{avg\text{-}amb\text{-}day}$ was observed in May being 41.98 °C and the lowest was in January being 25.57 °C (Hasan et al, 2016 (b). Values of monthly average water temperature ($T_{avg\text{-}water\text{-}day}$) (blue line) and corresponding thermal gain (Q_c) for each building type are presented in Figure 6 at secondary and primary vertical axis respectively. For the lowest inlet water temperature, thermal gain (Q_c) is the maximum and vice versa, which complies with the heat transfer mechanism as the heat transfer rate increases with the increase in the difference of temperatures between the two media. Thus, thermal performance of the system will stay higher in winter which is coincidentally the maximum hot water demand regime eventually leading to the best collector performance.

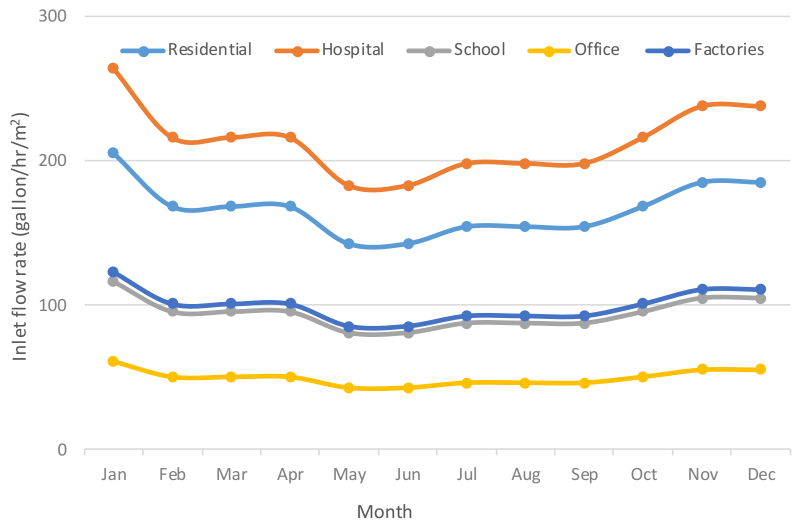

Figure 5: Monthly average inlet water flow rate for residential, hospital, school, office, and Industrial sectors.

Overall system performance

To evaluate the energy performance of the solar collector, the required water (ASHRAE Handbook, 2011) and temperature ranges (The engineering toolbox, 2016) were finally simulated with the optimized collector parameters and the yearly Q_c was determined for all building types summarised in Table 3. The hospital was the highest while the office was the least hot water consumers with the water temperature demand of 65°C and 45°C respectively. Hospital saved 23% while office saved 57% energy required for hot water production by incorporating solar thermal collector as presented in Table 3.

Conclusion

This current research has examined the energy performance of SWHS in various building types in the hot climate of Abu Dhabi, through TRNSYS simulation model. The simulation campaign has yielded in optimal collector tilt angle, azimuth angle and collector inlet water flow rate with respect to different seasons and building types represented by water demands. An optimal tilt angle of each month is identified to exploit the maximum potential of the system for the studied location, Abu Dhabi, UAE which ranged from 50° at maximum for

January to 0° for May. The optimum azimuth angle was found to be β= 0°for south facing while a 22% and 30 % drop in thermal yield was observed when the collector faced exact East and West respectively. It is observed that the wall mounted collectors are least effective compared to the flat roof and pitched-roof integrated systems. Additionally, the collector area required per building area shows that the hospital exhibits the highest collector area compared to building area. It is observed that an auxiliary heating source is required to compensate the temperature fluctuation as well as to provide a continuous supply of hot water throughout the year. The current study only limits itself with energy gains and is limited in scope. In order to practically apply the observed findings, further study is underway to compare the cost and benefit analysis of the proposed interventions.

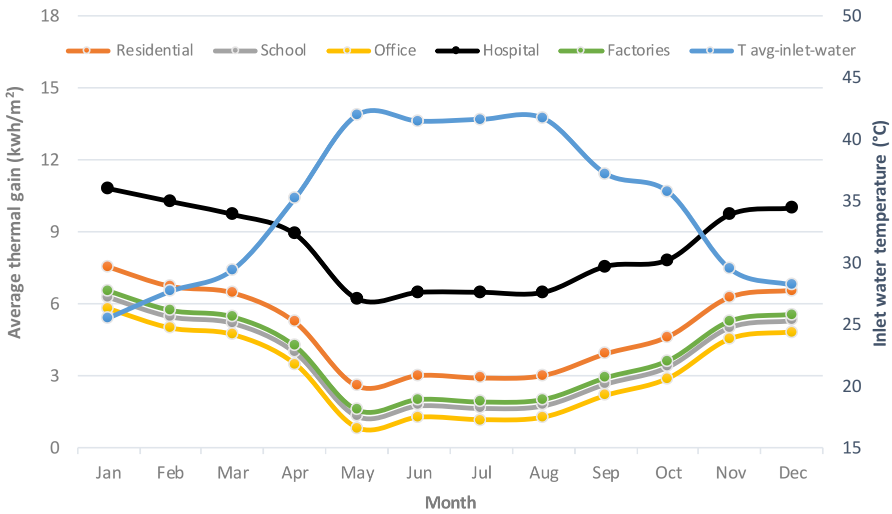

Figure 6: Average energy contribution from solar collector with varying inlet temperature

Table 3: Energy contribution from solar the collector

	Energy Performance (%)
Building Type	Static
Residential	34
Hospital	23
School	48
Office	57
Factories	45

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Legislation, Strategies and Incentives to Solar Energy Adoption by Apartment Buildings in Rio de Janeiro, Brazil

Marcelo de Mattos Bezerra[1] and Alfredo Jefferson de Oliveira[2]

[1] Department of Architecture and Urbanism, PUC-Rio – Pontifícia Universidade Católica do Rio de Janeiro, Rio de Janeiro, Brazil
[2] Department of Arts and Design, PUC-Rio – Pontifícia Universidade Católica do Rio de Janeiro, Rio de Janeiro, Brazil

Abstract: Brazil has one of the highest rates of sunlight in the world and Rio de Janeiro could be a leader in solar energy adoption in the country. This Paper presents the current situation of solar power in buildings in Rio de Janeiro, Brazil. Besides photovoltaic power systems - energy generation - energy consumption for providing hot water in the residential sector makes up 26% in the southeast of Brazil. In addition to solar panels, solar power is suitable for water heating. This is a bibliographical and exploratory research paper. Some interviews with Brazilian solar energy specialists are put forward. The main topic will be the legislation, strategies and incentives towards large-scale adoption in the city of Rio de Janeiro with smart grid concepts. The paper introduces a discussion and some comparisons on the main topics in Rio de Janeiro with a few cities and countries to propose some new approaches and items to increase adoption. To conclude this paper will propose improvements for the government and municipality to reach a new level in solar energy and thermal systems.

Keywords: Solar Power, Sustainable Construction, Apartment Buildings, Rio de Janeiro

Introduction

“Solar energy is the most abundant energy resource on the planet and is available for direct (solar radiation) and indirect (wind, biomass, hydraulic, etc.) use. The Brazilian approach is directed towards the use of solar energy in both ways, for both heating and lighting, using two routes: the thermal route mainly for heating and for the generation of electricity, in particular via photovoltaic panels for various uses such as lighting, pumping and communication.” (PEREIRA et al., 2012)

The first five countries as to installed solar electrical power capacity - Germany, China, Italy, Japan and the United States - produce 70% of the world total. In 2018, it is expected that Brazil will be among the top 20 countries for solar power generation (BRAZIL, 2015).

Solar irradiance in Brazil varies between 4,200 and 6,700 kWh/m2 per year, higher than that existing in countries known for the use of solar power, such as Germany between 900 and 1,250 kWh/m2 per year, France between 900 and 1,650 kWh/m2 per year and Spain between 1,200 and 1,850 kWh/m2 per year (PEREIRA et al., 2006).

According to the International Energy Agency (IEA, 2010, apud in EPE, 2014), systems in residential and commercial buildings should correspond, in 2020, to approximately 60% of photovoltaic power generation and photovoltaic power stations to 30% of the total. This projection demonstrates the attractiveness of small-sized systems this decade with a cost reduction trend for setup (EPE, 2014).

Buildings consume energy both during the construction period and throughout their useful lifespan. In Brazil, the percentage of electric power consumed by (commercial, residential and public) buildings is 47.6% (EPE, 2013). Out of the total energy produced in Brazil, 23.3% is used by the residential sector with the following distribution nationally and in the Southeast Region (see Figure 1) where the state and city of Rio de Janeiro are located (LAMBERTS; DUTRA; PEREIRA, 2014):

Table 1. Distribution of Power Consumption in Brazil and Southeast Region in the Residential Sector

	Brazil	Southeast
Refrigeration (refrigerator and freezer)	27%	27%
Water Heating	24%	26%
Lighting	14%	14%
Air Conditioning	20%	11%
Other (washing machine, iron, hi-fi, microwave, TV, etc.)	15.5%	17.2%

In Brazil, a large part of power generation comes from hydroelectric power stations, however there are challenges with this model, since only large-scale facilities are constructed and they are situated far from various points of consumption, thereby requiring high-cost infrastructure as to construction and maintenance. Besides this fact, there are also various consequences from the flooding of productive and previously occupied areas. It is worth reiterating that all the forms of power generation, even renewables, have pros and cons, but their combining and the proper case-by-case selection will be important to determine the best model with a combination of them.

Figure 1. Brazilian Southeast Region indicated in black

In Brazil, besides photovoltaic systems, a solar-derived solution is solar water heating, since even though Brazil is a tropical country, hot water is always used in homes and apartment buildings. Electric power and (oil-based) natural gas are used. One of the attributes of adopting solar water heating is the estimated payback time.

In apartment buildings in the city of Rio de Janeiro, penthouses and roofs are used privately and collectively, mainly as follows: when private, as penthouses or premises of ordinary apartments and, when collective, as common areas for residents, service areas (water tank, lift machine room, among others) or just roof tiling. Among new demands and potential uses, green roofs and vegetable gardens, rainwater catchment systems (for possible reuse), solar panels and solar water heating systems stand out.

The growth in the use of air conditioning due to the failure to adapt buildings to the climate and trend towards increasing average temperatures due to global warning command attention (LAMBERTS, DUTRA, PEREIRA, 2014). In addition, it is relevant that the highest levels of sunlight occur in the hottest regions and seasons, making them suited to photovoltaic systems that could be used for cooling systems.

The estimated photovoltaic generation capacity on roofs of residential buildings in Brazil is approximately 287 TWh per year, 2.3 times more than residential electricity consumption in 2013, demonstrating that distributed photovoltaic power generation in these same buildings could supply their portion of demand (GREENPEACE, 2016).

The National Electric Power Agency (ANEEL) foresees that by 2024 the number of consumers / electricity generators will be around 1.2 million, with solar power leading, thereby indicating exponential growth even during the current time of crisis in Brazil.

Various countries have been following policies incentivising the use of alternative sources, such as solar power, instead of fossil fuels, with 395% expansion by solar power in the form of photovoltaic panels between 2003 and 2013 (FONTES, 2017). EPE (2014, apud in FONTES, 2017) also highlights the role of source incentive programmes promoted by countries such as Germany, Australia, China, Spain and the United States. Technological development has occurred mainly in Germany, the United States and Japan and secondarily in Italy, Spain and Norway. Despite this, Esposito & Fuchs (2013, apud in FONTES, 2017) stress that studies for technological development in the photovoltaic industry are concentrated in China, the current leader in the production of solar panels.

Solar Power Scenario in Brazil and Rio de Janeiro

In Brazil, there is between 4.5 kWh/m2 and 6.3 kWh/ m2 of sunlight a day (COLLE et al., 1998 apud HASHIMURA, 2012). Based on a comparative analysis, the sunniest place in Germany, the country investing most in solar power, receives 40% less radiation that the least sunny area in Brazil. In Brazil, for a long time photovoltaic solar power has been associated with rural development programmes and access to electricity in isolated locations (HASHIMURA, 2012).

To generate the power consumed in Brazil in 2010 (455.7 TWh) 3,844 km² of solar panels would be necessary, corresponding to 0.045% of Brazilian territory (RÜTHER, 2012 apud in TORRES, 2012), which demonstrates the potential of this alternative.

As expected, on a city basis, the greatest potential is observed in the urban areas of large cities, where there is greater availability of housing, the installation of panels in buildings representing a very interesting function. As an example, the largest state capital in the country, São Paulo, has a potential equivalent to a tenth of the installed capacity worldwide in 2010 (MIRANDA, 2013).

According to the Empresa de Pesquisa Energética [Energy Research Company], producing power in Brazil from solar panels installed on building roofs costs less than the power sold by 10 of the 63 electric utilities companies in Brazil. According to data from 2012, electricity from a 5 kW solar system cost approximately BRL 602.00 (US$ 299) per MWh, while providers charge between BRL 240.00 (US$ 199) and BRL 709.00 (US$ 352) for residential power. The solar option on roofs is increasingly more competitive when compared with electricity from public utility companies. The cost of electricity in the residential sector in Rio de Janeiro is BRL 521.00 (US$ 258) per MWh, the average price with respect to what utility providers charge in Brazil. The cost of electricity in the business sector is BRL 470.00 (US$ 233), both substantially less than electricity generated by photovoltaic solar power (RIO, 2012).

Rio de Janeiro receives annually 1.7 MW/m2 in solar radiation (Meteonorm data), with daily average irradiation of 5.18 kWh/m2 (BLUESOL, 2017), while the city of Rio de Janeiro receives on average 4.63 kWh/m2 of solar energy per day (RIO, 2012). Currently, the

State of Rio de Janeiro holds fourth place in installed photovoltaic systems, with more than 600 systems (BLUESOL, 2017).

The city's design and the model of occupying the roofs of apartment buildings combined with sun exposure challenges in roof areas may give rise to a solar power inclusion strategy and policy in urban areas. The city of Rio de Janeiro has a large number of buildings existing in consolidated neighbourhoods. Buildings have diverse heights and are close to mountains in various locations causing shading that reduces the catchment yield potential. On the other hand, combination with other demands (commented upon in the Introduction) such as green and rainwater catchment areas will be decisive for the success of a solar power inclusion drive.

It is worth highlighting that for new buildings there is the need for designs to envisage already the system from the beginning and a necessary overhaul of legislation for buildings, in line with the combination vision suggested above among the solutions. For existing buildings, some flexibility must be added to the legislation.

An important vision for existing buildings will be to take action, in consolidated neighbourhoods, in city blocks with projects integrating various buildings, in many neighbourhoods with the same heights and project solutions (BEZERRA; OLIVEIRA, mar. 2016).

In the city, there is a sustainability-related qualification named Qualiverde, launched in 2012 by the City Council, with points for the inclusion, among others, of renewable power systems and solar water heating. Nevertheless, this qualification has not been adopted on a large scale, since it established incentives for buildings with increases in areas and other aspects and mainly reductions in taxes for construction and future housing units, all not yet approved (BEZERRA; OLIVEIRA, Sept. 2016).

Incentives, Legislation and Laws

Due to the need for diversification in energy sources, Germany, Spain, Italy, USA and Japan stand out due to the incentives from government subsidies for expanding the use of renewable power sources with government programmes incentivising the use of photovoltaic solar power, making them the biggest powers in the quality of installed solar panels worldwide (TORRES, 2012).

The 100,000 Roofs Programme implemented in Germany between 1999 and 2003, considered the biggest programme in the world for the introduction of photovoltaic solar power, made loans available to the population for the installation of systems connected to the power grid. The support framework involving subsidised loans was renamed subsequently to Solarstrom Erzeugen - Solar Power Generation (JANNUZZI, 2009 apud TORRES, 2012).

In 1995, by way of Law no. 9074, the status of Independent Energy Producer (PIE) was established, starting Brazil's path towards home power generation. By compensating for the energy cost involved, in this way it ensured for producers unrestricted access to SIN (National Interconnected System), which coordinates and controls the system, made up of national companies for the production and distribution of electricity in Brazil. In 1996 (Law no. 9427), ANEEL (National Electric Power Agency) was founded, a fundamental agent in the solar scenario (ALVES, 2014).

In 1997, CONFAZ (National Council for Treasury Policy) - by way of Accord no. 101 - granted an exemption on the Sales Tax (ICMS) for transactions involving equipment used for solar and wind power generation (SILVA, 2017).

The National Climate Change Plan (PNMC), created in 2008 by the Federal Government, had the main aim of promoting domestic actions contributing to the minimisation of climate changes, such as the expansion of the photovoltaic solar power industry and rural electrification development.

Resolution no. 482 dated 2012, created by ANEEL, establishes general conditions for micro and mini generation of electrical power and draws up so-called "Net Metering". The System makes it possible for consumers to install systems connected to the public power grid, being compensated for all generated power placed on the grid. Enterprises must have a maximum output of 1,000 kW (1 MW). If one installs solar panels, one may save up to 95% in electricity bills (ALVES, 2014).

In 2015, the Ministry of Mines and Energy (MME) launched the Development Programme for Distributed Generation of Electric Power (ProGD), with the objective of incentivising the use of solar power generation. The Programme expects an investment in the sector of approximately BRL 100 billion by 2030. Currently, Brazilian consumers benefit from various tax exemptions as to generated power. By way of Law no. 13.169, PIS [Social Integration Programme] and COFINS [Contribution for Financing Social Security] are exempted nationwide by the government. By way of the accord created by CONFAZ, ICMS is also exempt. In addition, there is also a reduction in IPI [Tax on Industrialised Products] and a discount on TUST [Tariff on Transmission System Use]/TUSD [Tariff on Distribution System Use].

ANEEL Regulatory Resolution 687 of 2015 creates shared generation characterised by the bringing together of consumers, within the same franchise area, by way of a consortium or cooperative, with a consumer unit with micro or mini generation distributed to a different place from the consumer units where surplus energy is compensated (included by ANEEL Regulatory Resolution 687 dated 24/11/2015). Another procedure made possible by this same resolution was remote self-consumption which allows consumer units owned by the same Legal Entity or Individual owning a consumer unit with micro or mini generation in different places, within the same franchise or permit (utility provider) area, to compensate for the generated surplus (ANEEL, 2012).

In 2016, by way of Regulatory Resolution No. 687, the rules were improved and new generation forms were added, allowing greater benefits for consumers as to their own power generation systems, as building and condominium residents (BLUESOL, 2017).

There is the expectation of new incentives, undergoing study, with the use of FGTS (severance pay indemnity fund) for acquiring photovoltaic systems (BLUESOL, 2017).

Some cities and Brazilian states also have their own incentives, such as the city of São Paulo - capital of São Paulo, the state with the strongest economy in the country neighbouring Rio de Janeiro - with Law 14.459 of 2007, known as the "São Paulo Solar Law", which requires new buildings constructed in the capital to be prepared for the installation of solar water heating systems. Buildings with units featuring up to three bathrooms must possess infrastructure allowing for the installation of a thermal tank and solar panels for generating solar power. The law also requires the installation of the system in new residential - single or multifamily - buildings with four or more bathrooms per housing unit (TÉCHNE, 2009).

Perspectives of Specialists

This part of the text presents the results of questions put to specialists in solar power with different roles in the Brazilian market on the following topics:

Moment

Loys (2017) considers that "with the solar potential offered by Brazil and the rates or price structures that are being used, responsible for increasing energy, mainly residential and commercial energy," Brazil has the potential for much greater photovoltaic generation and should be positioned among the largest generating countries in the world. For Halfeld (2017), solar power continues to be a solution adopted by a minority, with financial reserves combined with investment analysis, not adverse to risk.

Calili (2017) evaluates that "despite achieving progress with Aneel Resolution 687/2015" (it altered points of Resolution 482/2012) and market growth in 2016 (...) "few projects are signed by installation companies, above all (...) small-sized." According to Rauschmayer (2017) in general, Brazil is still at a beginning stage in the centralised generation sector, but he is optimistic, in terms of distributed generation, commenting that last year there was approximate growth of 300% with respect to the previous year. Campos (2017) understands that the market for solar power in Brazil still faces some barriers, with a large part being the lack of tax incentives, since the end price for customers is still high.

Legislation for Apartment Buildings

Rauschmayer (2017) considers the legislation to be positive, due to allowing necessary actions in apartments such as the installation of systems on building roofs. Loys (2017) interprets that Brazil should already have established a "law requiring the use of this technology in residence and businesses, even on a small scale."

In the perspective of Calili (2017), the legislation is not effective, since "the net metering system established by Resolution 482 limits greater investment by residential and business consumers" and considers that, as exemplified by countries such as Germany and the UK, "liberalising the market is important, meaning making it possible to sell surplus energy, and not just using it for compensation" without limiting the installed capacity of equipment in this new context to average consumption. According to Halfeld (2017), despite allowing the use of photovoltaic energy, the legislation is very weak, since the actions rely on resolutions (482 and 687 mentioned), but which "can be cancelled or altered at any moment without notice."

Campos (2017) considers the legislation for housing to be effective, but with challenges in the circumstance of (condominium) residents generating their own energy because of the need for authorisation to place solar panels in a collective area.

Barriers

"Article five of Resolution 687 establishes that private enterprise is to be responsible for reinforcing the public grid in most cases", which combined with the lack of transparency of providers (utilities) results in "private enterprise having no interest in building photovoltaic power stations" (HALFELD, 2017). Loys (2017) indicates as the main barriers: "The lack of knowledge among consumers and mainly among professionals linked directly to projects, specifically architects and engineers", since he notes that it is rare for an architect or engineer to know how to use this technology in projects and absence of knowledge of the "multiple functions a panel can fill in a building."

Rauschmayer (2017) indicates as barriers a lack of financing and a difficulty in obtaining profits, with the way in which one pays in the insignificant reduction of the electricity bill, thereby not providing much incentive. Calili (2017) enumerates three large barriers: regulatory, as mentioned above; financial, needing specific lines of credit with attractive rates for entrepreneurs; and technical - currently the electrical grid, due to not being intelligent, limits greater reach by photovoltaic technology, due to the need for net metering installation. Campos (2017) adds the lack of tax incentives, the absence of "bank loans and complexity of unnecessary documents sent to utility providers."

Incentives, suggestions and references

Calili (2017) interprets that there are few incentives and that the Brazilian market is over-contracted, due to the economic crisis, seeing the need for "state and federal tax incentives for a more robust photovoltaic market to come about." Calili (2017) suggests "a improvement in the regulatory framework which clogs up the acceptance process for this source of generation by power distributors."

For Halfeld (2017), there are no differences in incentives with respect to housing types - individual or collective. It is not effective for all cases. Halfeld understands that "the best incentive is always tax-related. A reduction in IPTU [municipal property tax] for environmentally friendly buildings would be a great help." Halfeld continues by commenting that another solution, based on outside experiences, would be the freeing up of energy credit selling, under which, in countries such as the Netherlands, consumers can choose from which company to buy energy paying a transmission fee to the local distributor. In this way, the owner of a small solar park can generate power for numerous interested parties, improving competitiveness and reducing the cost of this item for the population.

Rauschmayer (2017) observes that "the incentive nowadays is an exemption to the tax on the equipment, which does not cover all the equipment," and suggests the use of subsidised credits or direct subsidies. Campos (2017) stresses that "the legislation does not differentiate between apartments or residences, what differentiates is the size of the equipment." Campos interprets that the main incentive for acceleration is to adopt a so-called "feed-in-tariff" policy, in which government pays the consumer for excess power with a special rate, however there is "a lot of apprehension about the (...) energy structure, without smart grid systems (...)" with the possibility of a collapse. Campos concludes that there is the need for an immediate investment by utilities to set up smart grid systems.

Germany is a benchmark for Loys (2017) and Campos (2017). Loys (2017) understands that "the government has introduced renewables or energy efficiency concepts in legislation or in certifications, but culturally Brazil is still a country with a lot of waste including in energy." Loys (2017) affirms that renewable energy providers should be able sell their surplus for a price above that of the energy purchased from electric utilities and consumers should have the possibility to choose the type of energy.

Conclusion

As evidenced, Brazil has huge potential to become a country where solar power makes up its main energy source.

Adoption in apartment buildings brings various advantages such as consumption at the same location of generation and reduction of dependence on infrastructure, but in cities, such as Rio de Janeiro, there are construction challenges, due to the use of roof areas for differing uses and to shading hindrances as a result of the buildings themselves and nature (mountains within the city perimeter).

There are laws, but they are still far from bringing about the scenario necessary for large-scale adoption. Based on the result of the survey on specialists, it was made clear that there is a total lack of effective incentives and an absence of dialogue among the various parties involved in the process: government, utilities, developers and designers.

There is also a dearth of research applied to the subject making it possible to quantify, simulate and test solutions integrated with existing and new buildings.

An integrated public policy will be the next fundamental step for the inclusion of solar power.

One of the next steps of this research group will be to analyse the potential of including and adopting solar power in consolidated neighbourhoods in the City such as Copacabana, an object already studied in previous research.

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Design to Thrive

The Process of Urban Regeneration as a Policy of Integral Improvement

Juan Carlos Gonzalez [1], Julian Fernando Villa [2] and Alexander Gonzalez [3]

[1] Faculty of Architecture and Design, Catholic University of Pereira, Pereira, Colombia, juanc.gonzalez@ucp.edu.co
[2] Faculty of Architecture and Design, Catholic University of Pereira, Pereira, Colombia, julian.villa@ucp.edu.co
[3] Faculty of Architecture, Universidad Pontificia Bolivariana, Medellin, Colombia

Abstract: The reuse and adaptation of existing urban infrastructure and the appropriate management of economic and social resources contribute to the sustainable development of a community, encouraging energy consumption habits, usage of resources for a systemic, sustainable and consolidated habitability at a neighbourhood of the city of Pereira, Colombia. The implementation of an appropriate policies and reactivation of a deteriorated areas of the city is an opportunity to establish an appropriate set of strategies and policies, as a planning instrument of the territory. The fundamental concepts of urban regeneration transcend the need for a modernization, becoming catalysts of sustainable policy management, urban sustainable development, conducive to change the linear cycle of construction for a renewable system of sustainable construction. The process of urban regeneration as a policy of integral improvement and planning explores the economic, cultural, social and physical reactivation of a sector in the city, starts with the implementation of glocalized policies of urban resources, arranged by concerted acts that represent the state, public agencies, communities, and economic investors.

Keywords: Latin American Urban Regeneration, Local Urban Sustainable Development, Glocalization, Community Sustainable Policies

Introduction

Latin American cities establish their own dynamics of urban planning such as: changes in land use, habitability, mobility, expansion, reactivation and influence on environmental, economic, social and cultural aspects at populated city center. The Villavicencio commune is located adjacent to the downtown of Pereira, on the east side of the city. It comprises four neighbourhoods, Villavicencio, Berlin, Corocito and Los Andes. It is a dynamic sector that faces urban, social and environment deterioration as a result of insecurity, micro-traffic, insalubrity and lack of urban integration.

The Renewal Plan of Ciudad Victoria, favored migration and commerce to the Villavicencio commune, by evicting a social group that found a place on one of the oldest sectors of the city. The commune was the right place to settle down because of the urban fabric and land use configuration into low height buildings at not an expensive value.

The urban landscape is modified architecturally, with interventions in constructions that occupy new social groups. This architecture is often rewritten on the buildings occupied in order to provide a cultural "identity" to that inhabited landscape. (Gutierrez, 2012)

The revitalization and modernization of The Villavicencio commune, with polices of urban regeneration, proposes to identify a strategy applied to cultural, social and economic variables to allow an improvement on its urban structure and configuration. The upgrading of the neighbourhood, starts from its own demands to be carry out as a collective effort, to contribute with measures and guidelines applied to the specific demands.

Urban regeneration consists of an integral development and schemes of creation of sources of work to increase housing to overcome local social problems where multiple disadvantages are concentrated (European Commission, 1997).

The identification of the strengths and opportunities of participatory action originates an individual actions that involves technical and social strategies of analysis such as the integration between human factors and the environment, implementation of territorial planning models.

The sustainability associated with supporting aims to empower the inhabitant in urban decisions, establishing actions and procedures oriented by these individuals to devise the economic, social and environmental viability of their territory. "The regional and local powers have a fundamental role in working, in urban regeneration tasks, from territorial planning to urban development and its implementation, focusing on such tasks, the permanence of regeneration, new urban development And the benefit of the existing city in relation to urban expansion. " (Committee of the Regions, 2010).

Local community initiatives are created anonymously by bottom-up residents, sometimes locally implemented by public agencies or by national voluntary organizations from top to bottom. All are linked voluntarily (without remuneration) in an effort made by local communities. (European Commission, 1997).

The result of energy exchange between the atmosphere and the soil is palpable in the microclimate of the Villavicencio commune, in response to its own geographic, topographic and climate characteristics. The local sustainability is connected to the microclimatic conditions and its influence on inhabitants, buildings and public space.

Adapting to the environment means low-impact urban interventions, in some circumstances like green facades, these specific measures of the place contribute to the configuration of the microclimate, the urban environment or a neighbourhood. The small scale presents tools of analysis, of the different local characteristics like, the microclimate, and it is necessary to understand aspects like, the solar exposition and the wind patterns around the buildings. If not mapped, the microclimate before beginning its work, could choose the wrong procedures (Lenzholzer, 2015)

Urban regeneration procedures need to evaluate and to implement management techniques of microclimatic particularities such as radiation, air temperature, relative humidity, wind patterns, thermal conductivity of materials and human factors to strengthen a local strategy that adapts its policies in the improvement of processes of sustainable management.

Urban sustainability depends on the understanding of human factors and the capacity to mediate between the climatic effects necessary in the urban planning to design and manage efficiently with the climate. An example of integration of policies and urban development is the Public Policy of Sustainable Construction for the Metropolitan Area of the Valley of Aburrá in Colombia, which establishes management plan and technical guidelines that allow to qualify the sustainability processes from the urban scale to the local for the conditions. (AMDVA-UPB, 2015)

Urban regeneration is a strategic activity, connecting short periods of time with measures for immediate difficulties and long-term estimates to avoid future problems. Focusing on getting a clear vision of what to do. It is concerned with setting priorities and making them possible. It proposes an interventionist approach, which is achieved by working societies, trying to benefit a wide range of organizations, agencies and communities. It can be measured, evaluated and reviewed. It is related to specific and potential needs in a particular region, city, district or neighbourhood. It is connected to other zonal policies and programs. (Roberts P, Skyes, H. 2016).

Sustainability and urban regeneration guidelines contribute into finding common objectives and solutions applied to social, economic and environmental development. For example, the reuse strategy at the Villavicencio commune as a sustainable policy contributes to eliminate new constructions, reducing the effect on the carbon footprint and prolonging the life cycle of materials over time, preserving the social cohesion of communities and reactivating the economic growth of activities in the sector by promoting new land uses and maintaining ownership of land while avoiding gentrification.

New policies of sustainable development at the Villavicencio commune establishes a frame of reference where the processes of Management in Urban Regeneration could be implemented and their models integrate social, economic and environmental variables for the development of sustainable development with an efficient improvement and modernization of the urban structure. A new Urban Regeneration plan should be implemented and their models to integrate social, economic and environmental variables for the development of sustainable conditions with an efficient improvement and modernization of the urban structure.

Low-carbon regeneration schemes are poised to become more common as cities are increasing their leadership role in addressing climate change, omitting national governments and taking action even in the absence of legality and international blindness of Agreements. (Jones, P. 2013)

Sustainable Urban Regeneration provides management tools for intermediate cities to be attractive for urban development, and to recuperate quality of life to benefit its population, enhancing economic and social development to connect with other urban center.

Integral Improvement of Neiborghoods, MIB as an Urban Regeneration policies.

Figure 1. Before and After Bello Horizonte Neighbourhood, Pereira. (Ministerio de Vivienda de Colombia)

Intervention on existing urban structures with high levels of physical and social degradation have been carried out as a policy of urban development in Colombia since 1950.

Deteriorated sectors of the cities have had little improvement on processes of transformation and modernization, generating static physical structures with limitations in the generation of territorial development opportunities. Integral Improvement of Neiborghoods, MIB is a city plan of ordinances oriented to improve the physical urban structure of a city sector in decay. As a set of policies is not a regeneration procedures because in most cases do not involve communities participation as a City Planning establishes the borders of intervention.

In 1951, the municipal administration of Bogota, carried out an agreement with the center for formation and training of technicians, CNVA. To generate a reference of intervention to improve of the housing conditions, creating "programs of emergency". This policy were developed in two moments, the first intervention focused on rehabilitation, improvement and eradication of parts of the city which have poor physical conditions and the second, prevention seeking to limit the emergence of new settlements in precarious conditions. The interventions carried out by the emergency programs were focused on improving the physical conditions of the identified settlements. The improvement of neighbourhoods with basic services of infrastructures at consolidated neighbourhoods, and the rehabilitation of neighbourhoods focused on legalization, the generation of urban norm, the endowment of infrastructure and the construction of housing. The eradication of slums implied the transfer of families due to their location in non-urbanized soils due to risk conditions or the impossibility of providing public services.

Table 1. Guidelines Policy Consolidation of Integral improvement of districts for Colombia. (CONPES 3604)

Risk Intervention	***PUBLIC SCOPE***	Focuses on the intervention of the urban structuring systems that make up the physical environment of the intervention area.	Actions that eliminate the risk conditions of the population, from works of mitigation or relocation of housing.
Ordinances			Actions of planning from projects that allow the legalization and regularization of settlements.
Public Residential Services			Scope of work that allow the consolidation of basic services of water, energy and sanitation to guarantee the habitability and health of the settlements.
Recovery and Environmental Protection			Actions on the management of areas not susceptible to urbanization before they are invaded to preserve their value within the urban fabric of the city.
Accessibility and Mobility			Actions that allow an adequate mobility within the intervention area and connect in an integral way to the rest of the city.
Public Open Space and Equipment			Actions to consolidate the systems that provide services to the population to guarantee the consolidation of the settlement.
Titling	***PRIVATE SCOPE***	Focuses on the intervention of the complementary structured systems, mainly residential buildings present in the area of intervention.	Direct actions that allow the security on the property, generating tranquility and rooting among the inhabitants of the area of intervention.
Improvement of Housing			Actions for the improvement of housing in health, protection and operation.
Re-densification with New Housing Developments			Recomposing the urban structure requires a differential and more effective use of the land, so re-densification actions allow the resettlement and the opening of the area of intervention to new inhabitants.
Community Participation	***SOCIAL & ECONOMIC SCOPE***	Focuses on the transversal actions of social, cultural and/or economic character that allow to involve the community in the process.	Actions that are in a transversal way to the physical transformation, activate the interest of the community to improve, conserve and develop the characteristics of the settlement.
Institutional Strengthening			Actions that allow the presence of the public administration from services and activities that generate meetings between the parties in search of the permanent development of the community.
Security and Coexistence			Actions that seek to improve the quality of life of people, seeking the consolidation of a community in peace.
Generation of Income			Actions that allow the economic development of the population, which allows more purchasing power to improve their habitat and the eradication of illegal activities within the community.

Nevertheless, the practical development of programs determines the importance of social work to prevent and eliminate negative social conditions, such as generation of vicious circles. Granting stimulus by programs that are population appreciated as an opportunity to generating improvements to precarious conditions, as Eric Carlson says, "any urban renewal program must take into account human aspects and the importance of the group's work as an essential part of physical planning" ICT, 1966: IX (Torres , 2009)

CONPES 3604, defines a set of guidelines for the consolidation of the policy of integral improvement of districts, establishes the program's performance in three broad areas, including the areas of intervention public and private, the social responding to the human dynamics existing in the intervened sectors.

CONPES establishes elements required for the development of programs for integral improvement of neighbourhoods, MIB. Beginning with the studies to establish the tangible and intangible conditions of the settlement, going through the articulation with the territorial planning, with the capacity to provide structuring systems in public space, public services, and environmental management of the municipality to determine the environmental risk conditions to the settlement. The figure 2, Cycle Program Integral Improvement of Neighbourhoods shows the procedure established for this type of interventions in two possible actions on the territory depending on the requirements and needs of the same, the first an improvement properly said, and the second the resettlement of the population when it is required.

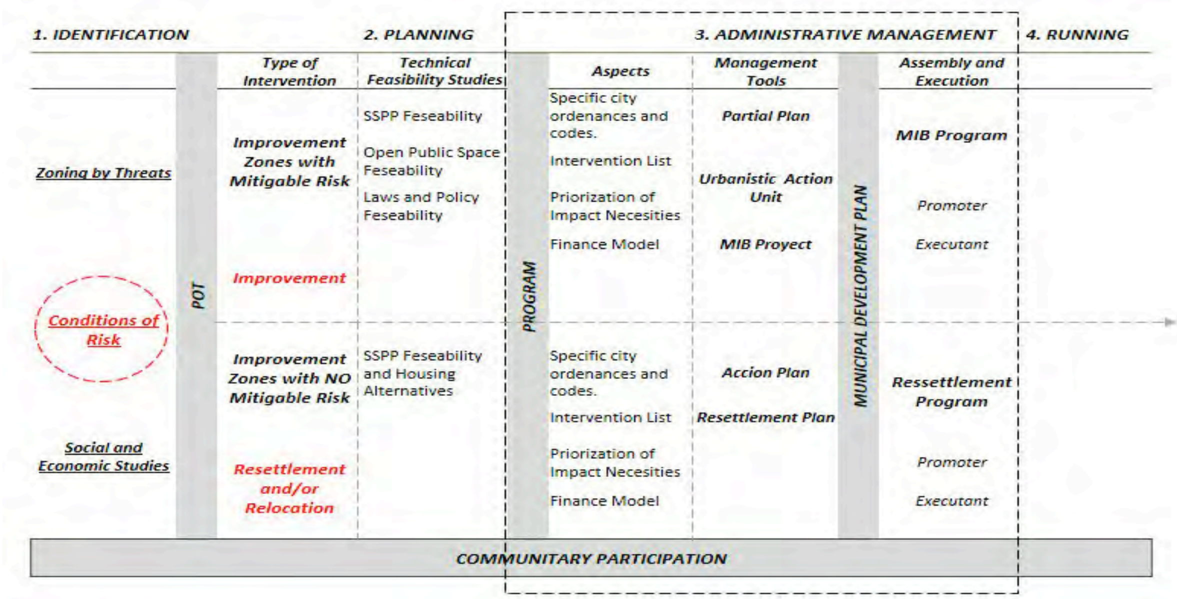

Figure 2. Cycle Program for Integral Improvement of Neighbourhoods – MIB (NDP, 2009)

The city of Pereira have developed two urban interventions with different results. First was a MIB at Bello Horizonte at the Cuba Commune on the west side of the city. The second was Ciudad Victoria, an urban renovation plan next to the Villavicencio commune. See table 2 for a parallel figure between urban interventions in the relevance of actions.

Table 2. Parallel of Urban Interventions at the City of Pereira, Colombia

		BELLO HORIZONTE	***CIUDAD VICTORIA***	***VILLAVICENCIO COMMUNE***
Risk Intervention	*PUBLIC SCOPE*	Areas of risk are established and work is done with the community for protection.	The areas of the Egoya collector are determined and established as public space.	There is a condition of slope that causes the re-localization of housing. Measures not in place.
Ordinances		A surgical order is made to improve the existing conditions, respecting the maximum the settlement.	An order is made that does not take into account what exists	Local city ordinances should be applied such as POT and Partial Plans.
Public Residential Services		The infrastructure is provided to the neighborhood to consolidate the provision of the service with quality.	The location of the area guarantees the availability of the service. The intervention focuses on the modernization of the networks.	The area has a respectable network of services. It requires to legalize service at informal housing.
Recovery and Environmental		The perimeter green areas and a public recreational area are consolidated.	It consolidates the public space around the protection floor.	The area around the Egoya fault must be consolidated.
Accessibility and Mobility		The road network is conditioned to guarantee pedestrian mobility and public and private vehicular transport.	The road mesh is conditioned to guarantee pedestrian mobility and public and private vehicular transport.	To connect the existing system to the city grid. Pedestrian paths are fragmented with opportunities of consolidation at city block centers
Public Open Space and Equipment		It creates a recreational public space, a synthetic football pitch, and a small covered meeting space that are physically connected by a Pompeian.	The Victoria Civic Square and the Lucy Tejada Cultural Center are created.	There are no consolidated connections between public spaces. To improve existing recreational spaces.
Community Participation	*SOCIAL & ECONOMIC SCOPE*	The community is actively involved in the whole process.	Did not take into account the existing population of the area; a displacement was generated with homeless population and drug addicts.	There are several organized groups that represent the interests of the population and seek community welfare.
Institutional Strengthening		Consolidated board of local action. Currently has a representative of the community in the Municipal Council.	There is no action. It is well balanced by the central location of the intervention area.	There is no quantification for this characteristic.
Security and Coexistence		The permanent work with a community allowed integration and social controls.	This is not addressed in the process.	There is no security due to the lack of coverage of the service.
Generation of Income		Working with the community, the urban structure is transformed to generate new trades around the centrality.	New developments such as mall and anchor retail store were developed. This is not addressed in the process.	Informal resources.
Titling	*PRIVATE SCOPE*	A titling process is generated for families who demonstrate the required legal conditions.	It is not required. Property integration is sought, but has not been developed.	It is required a titling because there are some areas with not legal housing at risk conditions.
Improvement of Housing		The improvement actions are carried out to the dwellings that present the worst conditions of habitability.	No action is foreseen inside the existing buildings, the total renovation is sought.	Improvement measures are required at existing housing.
Re-densification New Housing Developments		There are no new housing projects.	New housing projects are truncated by the economic speculation of the land and management of the municipal administration.	Low-rise buildings are predominant. The real estate market wants to densification in height.

The Social and economic environment strength of the MIB planning is to integrate the public and the private sectors to solve with creativity, ingenuity, an adequate budget physical conditions in an integral way of sustainable planning. Another way of taking actions of sustainable development, can be acquire with the implementation of policies based on indicators that characterized of the quality of life and services for a smart city.

International standards for the sustainable development were develop by the International Organization for Standardization, ISO on its standard number 37120:2014. The applicability of these standards provides valuable information of analysis looking forward sustainable development strategies. A smart neighbourhood recognizes its efficiency to improve quality of life, and services where a sustainable indicators provides an understanding of direct actions for a feasible strategies, to investigate variables that reflect the appropriation of sustainable development by their population.

The ISO 37120:2014 contemplates indicators that can be transferred from the international standards to local policies. To diagnose the urban sustainable development of improvement of the Villavicencio commune. It’s important to assess a standard analysis that allow to classified local data and to produce a methodology guide to categorize variables.

Table 3. Comparison of Indicators of Sustainable Development

	ISO 37120 : 2014	***VILLAVICENCIO COMMUNE***
1. Economy	Unemployment data, levels of poverty, a percentage of young unemployment and full time employees, number of business and number of new patents.	Unemployment makes measurement difficult because informal work is one of the main sources of resources for the population.
2. Education	Female students percentages, number of students who complete the Elementary, Secondary & University. Includes a ratio of student / professor at elementary school.	The neighborhood has three educational institutions for primary and secondary to cover the population. The majority of the population do not have university education.
3. Energy	It determines the access to service, energy consumption and the interruption of service during a year.	It has stratification in the cost in relation to the city. There is no alternative of energy production, nor incentive policies to reduce consumption.
4. Environment	It measures the amount of harmful particles and greenhouse gas emissions in tons per capita, nitrogen dioxide concentration, sulphur dioxide, ozone concentration and noise levels impact.	Requires studies to determine the air quality and the effects of gases generated by the small and medium industries of the sector.
5. Finance	Debt coverage indicator of debt, cash capacity to cover interests, bill rates and securities indicators.	The capacity of indebtedness is minimal because the majority of the population does not have access to bank credits due to the informality of their work.
6. Emergency	Amount of fires per each 100 miles/hectares, death by natural disasters per each 100 miles/hectares, prompt response by emergency calls, and response to first call from fire department.	There is a deficit in the provision of emergency services, since there are no first-level hospital or care centers. The deficiency of fire stations is generalized in a city.
7. Government	Measures the level of participation in the last municipal elections, rate of convictions for corruption per 100,000/ha and voters registered in relation to people of voting age.	Citizen participation is limited in women and young adults. The Corruption and crime is high. There is little representation of the population in government institutions.
8. Health	Life expectancy, number of hospital beds, number of doctors, percentage of under-five death rate, number of nurses, number of mental health professionals and suicide rates.	The basic health service is provided by health centers and not by hospitals since there are no first-level hospital in the area.
9. Recreation	It takes into account the amount of .2 m / person available for recreational spaces both indoors and indoors.	There are three parks in the sector but the public space deficit is high for the existing population.
10. Security	Number of police officers, number of suicides, crime rates against property. It takes into account the response time to calls to police before an event.	There is a deficit in security. There is a plan to build a new policy station in a selected neighborhood.
11. Shelters	It assesses the percentage of inhabitants living in poor neighborhoods, the number of "homeless", and the number of unregulated households.	New housing centers are needed because of proximity to Liberty Park which is well known area for homeless.
12. Waste Management	It measures the percentage of population with sanitation facilities, total solid waste collected by the municipality, waste sent to an incinerator or landfill. The capacity to generate hazardous waste in tons per capita is also calculated.	The commune is connected to the sewage system and rainwater collection of the city. There are no own policies for the management of waste or garbage.
13. TIC Innovation	Number of internet connections, the number of mobile telephone devices and the number of fixed telephone lines.	There is no quantification for this indicator. The internet service is contracted with particular providers of the service.
14. Transportation	Number of kilometers of high-capacity public transport network, number of journeys carried out by public transport, percentage of workers using a different mode of transport.	There is a limited service in public transportation. There are not bicycle lines.
15. Urban Planning	It measures the hectares of green areas, a number of trees planted annually, and the number of jobs per household.	No new areas has been created, existing infrastructure is maintained, community participation.
16. Water Management	Percentage of the population that has facilities for wastewater collection and the level of treatment of water purification.	There is no quantification for this indicator.
17. Potable Water & Sanitation	Percentage of population with drinking water facilities, consumption of drinking water per capita, number of hours of water service without interruption and percentage of water loss.	Drinking water is supplied by the city, there are sectors of the population located in areas of risk that do not have the service.

The implementation of indicators of sustainable development in cities, offers the possibility of developing methodologies and models that establish criteria of urban regeneration at the neighborhood level, that contribute into dimension and implementation of sustainable development policies of smart cities. These processes require the participation of professionals and community leaders incorporating trans-disciplinary strategies that guide decisions to obtain sustainable development indicators that respond to technical, economic, social, urban and environmental issues.

The findings in this study display significance of development regeneration strategies as a need to address an integral respond into the urban planning of neighbourhoods. The existing policies do not respond to criteria's about sustainability as challenge of designing existing sectors on cities includes to integrate social and economic, private, public participation of different groups of its community. To recognize renovation and regeneration planning as a mayor force of transformation of the existing urban fabric of neighbourhoods which contributes to the sustainable design of cities in Latin America as develop a responsible attitude about the preservation of the environment.

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Design to Thrive

Solar Thermal Venetian Blinds – Transparency, User Comfort and Solar Energy in one!

Simon Frederik Häringer[1], Ikbel Abderrahman[1], Puttakhun Vongsingha[2], Tilmann E. Kuhn[1], Paul-Rouven Denz[2], Christoph Maurer[1]

[1] Fraunhofer Institute for Solar Energy Systems ISE, Freiburg, Germany, simon.haeringer@ise.fraunhofer.de
[2] Facade-Lab GmbH, Am Wall 17, D-14979 Grossbeeren/Berlin, Germany

Abstract: Solar thermal venetian blinds (STVB) combine the switchable transparency and glare protection of venetian blinds with decreased temperatures of the interior glass pane and a supply of solar thermal heat. Venetian blinds placed between two glazing units as e.g. in closed-cavity façades can reach high temperatures. Removing the solar thermal heat from the slats reduces the temperature of the glass unit facing the interior which increases the thermal comfort for people inside the building. This also reduces the cooling load because less heat flows from the façade to the building interior. The solar thermal heat can be used e.g. for domestic hot water and dehumidification to reduce the carbon footprint of the building. Different varieties of STVB can be designed and two examples are presented to show the potential of STVB.
Heat pipes are used to transfer the absorbed solar energy from the slats to the vertical header tube. Heat pipes and header tube are connected by a dry switchable thermal coupling allowing full movement of the slats. As the STVB uses only few additional parts compared to conventional venetian blinds and focuses on mass-produced parts, it has the potential to offer a very competitive price for solar thermal heat.

Keywords: building-integrated solar thermal (BIST), solar thermal building envelope, thermal comfort, venetian blind, double-skin façade

Introduction

The development of solar thermal venetian blinds (STVB) pursues the idea to use the energetic potential of solar irradiation on transparent façades. STVB can enhance the functionality of venetian blinds by adding solar thermal collector functionality into it. Large transparent façade areas can thus actively contribute to a reduction of primary energy demand while having the same structure and benefits of the façade system. Furthermore STVB have the potential to improve the thermal comfort by lowering temperatures for venetian blinds mounted in between glass units as e.g. in double-skin façades.

Building-integrated solar thermal collectors (BIST) have saved 40% in the past compared to building-attached collectors installed after the initial construction (Cappel et al., 2015; Maurer et al., submitted). But space for opaque BIST is limited with modern architecture thriving for highly transparent façades. Especially in high-rise buildings, venetian blinds are often used in between an outer and inner glazing and can reach high temperatures due to solar irradiance (Gratia and Herde, 2007a). STVB could resolve this problem and reduce the heat flux to the building interior which decreases the cooling load.

State of the art

BIST & Transparency

The idea of removing solar thermal heat from the building envelope dates back to (Morse, 1881). Semi-transparent solar collector window systems were proposed by (Fuschillo, 1975). An overview of related research on Trombe walls, BIST air collectors, is presented by (Saadatian et al., 2012). BIST collectors for opaque building envelope areas are market-available in various forms (IEA SHC Task 51, 2016; Maurer et al., submitted). For transparent BIST, fewer technologies are available. A semi-transparent BIST with seasonal sun shading was invented by (Robin, 2002; Robin Sun) and installed in many buildings. Permasteelisa developed a semi-transparent BIST with small slats and seasonal shading (Maurer et al., 2013; Maurer et al., 2014). A semi-transparent BIST with vacuum tubes and perforated concentrator sheets is available from (Ritter XL Solar GmbH, 2017; Wolf and Molter, 2012). All previously listed collectors work with liquid as heat-transfer medium, whereas Kollektorfabrik developed a semi-transparent BIST which is used to heat air directly (Maurer et al., 2012). Two transparent BIST technologies using water in between glass units are under development (InDeWag, 2017; Stopper et al., 2013). This approach offers full visual contact to the exterior but lacks glare control and the solar thermal efficiency is small.

Several patents have been filed which claim or could be interpreted as solar thermal blinds, some of which appear to be tiltable like (Bittmann, 2006; Pierce, 1977). However none of the technologies known to the authors offer STVB that are both tiltable and retractable as proposed in this contribution. To the best of our knowledge only theoretical studies of fully tiltable and retractable STVB with liquid heat transfer medium have been published. Different theoretical approaches for solar thermal venetian blinds were discussed by (Cruz Lopez, 2011). Another theoretical study claims possible reduction of solar heat gain by 33% in Mediterranean climates for STVB in double-skin façades (Guardo et al., 2015). The STVB presented in this contribution aims to close this gap between theory and practice by employing a switchable thermal coupling.

Overheating of conventional venetian blinds in cavities

Venetian blinds placed in the cavity between an outer and inner glazing can experience a serious overheating problem. (Gratia and Herde, 2007a, 2007b) studied the effect of venetian blinds, their color and position and other parameters on cavity and blind temperatures and energy consumption in double-skin façades (DSF). Thermal comfort can be affected negatively if the temperatures of the glazing facing the room differ significantly from the air temperature and surface temperature of the room's walls as defined in the ISO standard 7730 (International Organization for Standardization, 2005).

Another drawback of high cavity temperatures is the additional stress it puts on components. In closed-cavity façades (CCF) this is particularly important as they by design lack the option for ventilation as possible for DSF and can reach temperatures up to 85°C (Lutz, 2012). New technical solutions were developed e.g. for the venetian blind mechanism to withstand the high temperatures (Schrag, 2015). Last but not least high cavity temperatures can also increase solar heat gains to the building interior (Gratia and Herde, 2007a). Depending on the U-value of the interior glazing a significant portion of the heat absorbed in the cavity can enter the building rather than being released to the environment.

Working principle of solar thermal venetian blinds

A typical façade element with a solar thermal venetian blind consists of an outer glazing and an inner double or triple glazing. The STVB is mounted in between the glass units as shown in Figure 1. The slats of the STVB absorb the incident sunlight. Different types of slat coatings can be used such as conventional or spectrally selective coatings with strong absorption. Solar heat pipes are used to extract the absorbed solar energy from the slats. Different heat pipe geometries can be used and either be attached to the bottom of the slat (e.g. cylindrical heat pipes) or used as slat itself (e.g. flat heat pipes). The heat pipes are connected to a vertical header tube placed in the façade element frame. The heat is transferred from the heat pipes to the fluid in the header tube via a dry connection. For this purpose a switchable thermal coupling is being developed and has been filed for a patent. This switchable thermal coupling transfers the heat when it is closed. If it is open the slats are free to move and can thus be tilted, raised and lowered as known from regular venetian blinds. To improve the thermal contact between each heat pipe and the header tube adapters can be used. The combination of using heat pipes and the switchable thermal coupling leads to having only two simple hydraulic connections per façade element and no flexible tubes. The STVB is designed to need as little maintenance as conventional solar thermal systems. A control strategy can be implemented to optimize thermal comfort, energy harvesting and user comfort considering daylight demand and glare protection. Ideally an automatic but user-adaptive control is used with purpose of maximizing user comfort and energy performance.

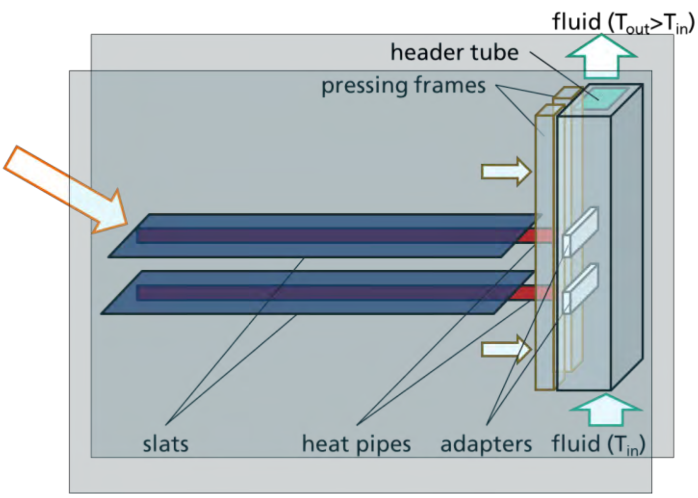

Figure 1: Working principle of solar thermal venetian blind

Solar heat pipes are well-known from their application for example in vacuum tube collectors. However operating these heat pipes in horizontal orientation is yet challenging and is currently being optimized for application in STVB. Another technical challenge is designing the switchable thermal coupling in a way that it provides good heat transfer, allows all slat movements and has the same service life as the façade at competitive costs. A test sample with two different mechanisms is being manufactured to gain more knowledge about feasibility and durability of the mechanisms (cf. section “First test sample”).

Potential benefits of solar thermal venetian blinds

STVB have the potential to integrate solar thermal functionality into transparent façade areas and to improve thermal comfort in the building interior. STVB are particularly interesting to be used in double-skin façades (DSF) and façades with box-type windows. Closed-cavity façades (CCF) as a subcategory of DSF are promising, as they provide a clean environment to the STVB and no soiling of the slats will occur. The overheating problem present in CCF could be reduced by using STVB. An ideal application of STVB would be a building with large transparent building envelope areas, significant demand for domestic hot water in which external blinds are not desired or feasible. The design of STVB has large freedom since it combines the design possibilities of venetian blinds (e.g. shape, geometry, top and bottom surface coating, cf. (Kuhn, 2017)) and adds a dimension for the solar thermal functionality which includes the choice of heat pipe, mechanism etc. To illustrate the large design variety of STVB a variant focusing on a *low g value* and a variant focusing on a *high solar thermal performance* are being discussed in the next two subsections.

Focus low g-value

The aim of the STVB variety *low g-value* is to minimize the solar gain to the building interior and maximize thermal comfort in the building. The primary purpose of the solar thermal functionality is thus to lower the slat and cavity temperatures. By lowering the cavity temperature less heat flows to the inside and the temperature of the interior glass unit is closer to room temperature. If the STVBs are lowered and closed very small g-values could be reached. This is possible because the STVB in this case acts as solar control device and as solar thermal collector, i.e. direct radiation is absorbed or reflected by the blinds and excess heat is removed. However the excess heat is not simply removed but turned into useful energy which could be used to heat domestic hot water or for solar dehumidification thus providing a renewable energy source.

Figure 2: Visualization of three different façades with STVB, variety *low g-value*

STVB aiming at minimal g-values should employ slats with a reflective coating to minimize the absorption of solar radiation in the cavity in the first hand (cf. Figure 2). To remove the absorbed energy efficiently the heat transfer from the slat through heat pipe and switchable thermal coupling into the fluid in the header tube needs to be good. The temperature of the fluid when entering the header tube at the bottom of the façade element should be low to extract as much heat as possible, i.e. to cool the slat effectively. Also the thermal insulation between cavity and interior needs to be large to ensure heat is removed via the header tube and not into the building. This means double or even triple glazing should be used for the interior glazing and also the frame should be well insulated. With outdoor temperatures comparable or higher than the cavity temperatures a good insulation to the exterior is preferable. For outdoor temperatures lower than cavity temperature a small insulation could be helpful in additionally removing heat from the cavity. This heat however is lost as it is not turned into useful energy. A control should aim at maximizing daylight while minimizing glare and overheating of the room.

A promising application case of this STVB is an office high-rise building with solar dehumidification. To prove the potential of the STVB future studies will compare a building with STVB with reference cases. Examples for reference cases include the same building with conventional blinds in the glazing cavity with or without improved solar control glazing or with less transparent areas in building envelope.

Focus solar thermal performance

The STVB variety *high solar thermal performance* aims at maximizing the collected solar energy in form of heat. The solar thermal functionality aims at significantly heating up the collector fluid, e.g. to use it to heat domestic hot water. The STVB thus has to be designed such that it absorbs a maximum amount of incident solar radiation and to minimize losses of this absorbed energy to the environment.

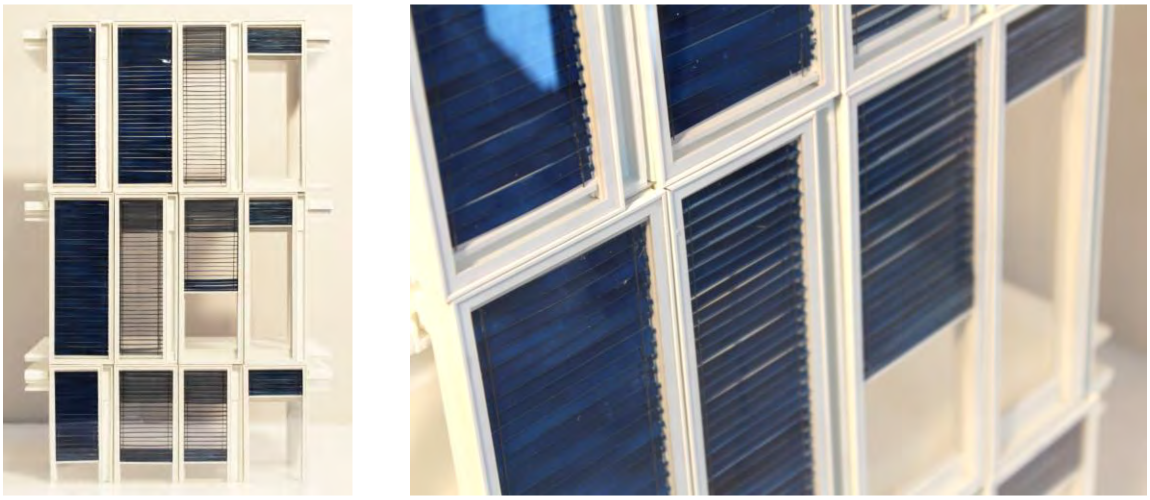

Figure 3: Architectural model of façade with *high solar thermal performance* STVB as presented at the trade fair BAU 2017 in Munich

High solar thermal performance STVB could use spectrally selective coating as known from conventional solar thermal collectors and photovoltaic cells. The appearance of this coating is dark blue as illustrated in Figure 3. The heat transfer between absorbing slat and fluid in the header tube should be maximized as in the *low g-value* variety. The fluid temperature at the inlet could be set to reach desirable outlet temperatures useful for its designated purpose such as heating domestic hot water. Here an optimization could take place with regard to maximizing the solar thermal performance and still maintaining a low g-value by operating the STVB at low fluid inlet temperatures. Insulation should be good to interior and exterior to minimize all losses. For the exterior glazing a trade-off has to be found between maximizing solar transmission and maximizing insulation properties with the overall goal of maximizing the solar thermal yield. If maximizing the solar thermal yield is the only criteria blinds should always be lowered and slats tilted to face the sun as proposed by (Cruz Lopez, 2011). However this is an impractical assumption. Daylight demand and user comfort should be taken into account and included in an automatic control that can be overruled by the user.

The application of the *high solar thermal performance* STVB would be promising for example in a high-rise building which is partly used as hotel. Reference cases for further studies aiming to prove the potential of this STVB could include the same building with conventional blind in the glazing cavity, or with conventional solar thermal collectors on opaque building envelope areas, or with stationary semi-transparent solar thermal collectors on opaque building envelope areas.

First test sample

Currently a laboratory test sample is being manufactured with the aim of testing the mechanisms of the switchable thermal coupling and the tilting and retracting of the slats. One particular configuration of the STVB was chosen for this test sample. A cylindrical heat pipe dummy of 10 mm diameter is attached diagonally to the bottom of the slat (cf. Figure 4). The diagonal configuration leads to a small operating angle of the heat pipe which improves its performance compared to horizontal orientation. Currently, flat heat pipes which work efficiently in horizontal orientation within the façade systems are under development. For the switchable thermal coupling an adapter between heat pipe and header tube was designed as visible in Figure 4. Two different mechanisms will be investigated for the switchable thermal coupling. Both aim at using a minimum amount of energy. For this purpose self-locking mechanisms were chosen that only require energy for the movement but none for the end positions *open* or *closed*. The first mechanism employs springs and self-locking solenoids, while the second mechanism uses a cam-shaft driven by a stepper motor.

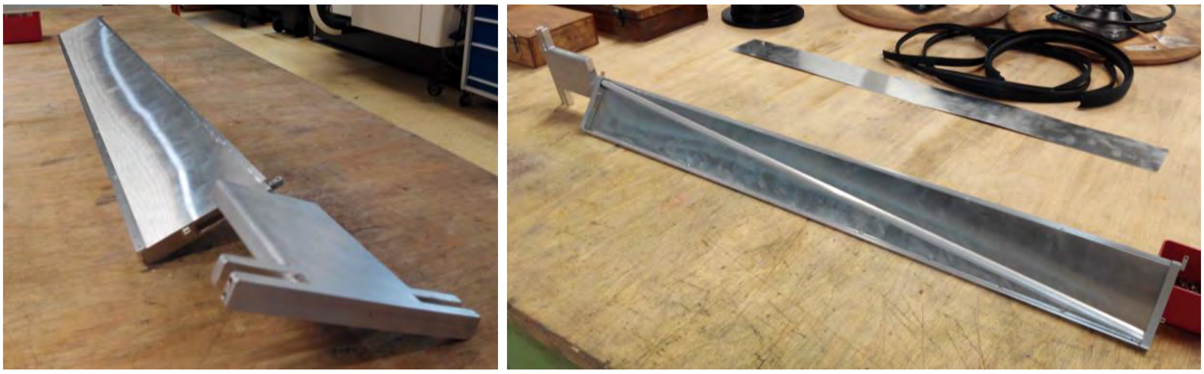

Figure 4: First produced slat of proof-of-concept test sample with adapter visible in the foreground (left) and bottom view with diagonal heat pipe mounting (right)

During the design of the test sample it was found that the slat design with the non-centered adapter poses a challenge to the tilting mechanism. This was resolved by moving the rotation axis of the slat into the actual center-of-mass of the slat assembly and adding mounting pieces to attach the tilting mechanism to the slat. Main focus during the testing period will be the reliability of the pressing mechanisms over many cycles of opening and closing the switchable thermal coupling combined with a large variety of blind movements.

Conclusion and outlook

The solar thermal venetian blinds offer the same flexibility as conventional venetian blinds and can improve the user comfort and the carbon footprint of the building additionally. With a few more components compared to conventional venetian blinds between glass units, STVBs can reduce the temperatures of the interior glass unit, the cooling demand and supply solar thermal heat to the building services. Many variants can be realized. Two promising cases are variants focusing on a *low g-value* and *high solar thermal performance*. Using heat pipes for the heat transfer and a switchable thermal coupling offers a safe and effective way to implement this functionality into a venetian blind. Two mechanisms for the switchable thermal coupling were developed and a test sample is currently being manufactured. It will be tested for reliability of the mechanism, especially with regard to the combination of blind mechanism and switchable thermal coupling mechanism.

Optimization of the slat in combination with improved horizontal heat pipe performance is an important next step in improving STVB. Thermal, energetic and optical measurements on a first STVB façade element are planned. The measurement results will then be used to calibrate a simulation model of STVB facades which can easily be used by planners to quantify the benefits of solar thermal venetian blinds for a specific building project. To enable the implementation of the system the constructional and architectural integration of STVB into the façade is developed in parallel to the technical aspects of the STVB itself. Finally, an integrated façade and building service solution for the STVB system should be designed to realize a holistic STVB façade solution in first reference projects.

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Increasing the Utilization of Local Energy Potentials through Low Temperature District Heating Networks

Karl Martin Heissler[1], Jakob Metz[1], Thomas Auer[1] and Isabell Nemeth[1,2]

[1] Centre for Sustainable Building, Munich School of Engineering, Technical University of Munich, Munich, Germany, martin.heissler@tum.de
[2] Sustainability – Focus Civil Engineering, Campus Feuchtwangen, Ansbach University of Applied Sciences, Ansbach, Germany

Abstract: The development of district heating networks over the last two centuries, changing from steam to pressurized water as medium for heat transport, has been an evolutionary process with various aims: preventing boiler explosions, raising comfort and saving fuels. With the substitution of steam, the supply temperature levels also decreased to 100°C or less, which led to fewer heat and process losses (Lund et al., 2014). However, the advantages of further lowering the supply temperatures to a level of 5°C to 40°C, especially in combination with solar thermal collectors, are unknown. In this paper, we present a modelling approach and a comparison of the thermal losses of a low temperature district heating network and a state-of-the-art district heating network. The thermal losses of the low temperature district heating network amount to 1.89 % of the district's total annual heat demand versus 12.97 % of thermal losses in a traditional district heating network. The results demonstrate how a further reduction of supply temperatures in district heating networks can reduce the thermal losses significantly and help district heating systems to become more energy efficient.

Keywords: Low temperature district heating networks, solar thermal, renewable energy, co-simulation, energy efficiency potential

Introduction

The 2015 United Nations Climate Change Conference set ambitious targets for the minimization of greenhouse gas emissions (United Nations, 2016). Every sector, especially the buildings sector with its 36 % of CO2 emissions share (European Commission, 2017), has to improve and become more energy efficient. Lowering the energy demand of buildings for space heating and domestic hot water production can therefore only be one piece in a puzzle that amongst other measures has to include the improvement of supply structure of buildings and districts. These were designed and built over the last two centuries, serving vastly different demands and requirements than those of today's energy efficient buildings. Currently, second generation district heating networks (DHNs), which are still in use, operate with supply temperatures of 100°C or higher (Lund et al., 2014). This leads to heat losses during transport due to the temperature difference with the surroundings. The DHN principle is to supply low mass flows at a high temperature level and to reduce these high temperatures on-site with mixing valves to a lower target temperature. For use in domestic hot water systems the supply temperature has to be reduced to a maximum of about 60°C. Low temperature district heating networks (LTDHNs) reverse this approach: cool supply temperatures in the network are lifted to the temperature levels needed precisely where and when they are needed (Sulzer & Hangartner, 2014). Previous studies examined LTDHNs supplied by groundwater heat and found a significant potential for the reduction of thermal losses by 25 % (Bestenlehner et al., 2014).

The approach of using a co-simulation environment of TRNSYS (Trnsys 17, 2014), BCVTB (Wetter et al., 2016) and Dymola (Dymola, 2016) allows the assessment of thermal losses of both DHNs and LTDHNs (Heissler et al., 2016). This simulation approach is expanded to enable an easier exchange of models within the frameworks and thus facilitate a comparison of the losses of DHNs and LTDHNs.

Methodology

Tools for modelling LTDHNs have to cope with highly dynamic and reversible flow conditions compared to traditional DHNs. The approach presented by Heissler et al. (2016) suggests a three-part simulation framework to cope with the various modelling requirements (Figure 1): Collector and Building Simulation, Interlink Zone, and Hydraulic Network and Storage Simulation.

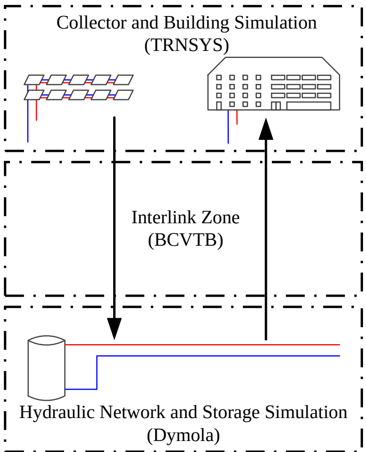

Figure 1. Simulation framework as proposed in Heissler et al. (2016)

In this work, we propose a separation of the Collector and Building Simulation into two parts: a Heat Demand Model and a Building Services Model. This allows for a more flexible approach and an easier exchange of models within the frameworks (Figure 2). Here, the Heat Demand Model is realized as an Excel Makro. The communication between the Building Services Model and the Hydraulic Network and Storage Simulation, which are implemented in two separate simulation environments TRNSYS and Dymola, is established by the tool BCVTB which enables data exchange during an ongoing simulation. With these simulation frameworks, two different types of networks, DHNs and LTDHNs can be compared. Both frameworks depicted in Figure 2 are supplied with identical weather data and heat demands. Each Building Services Model meets the heat demand by primarily using the local solar potential. If the heat demand cannot be covered locally, it is forwarded to the hydraulic network. The hydraulic network in turn meets this heat demand by circulating fluid through the loops supplying the buildings with heat. Depending on the temperature gradient between fluid and surroundings this fluid loses heat during transport. The aim of this paper is to compare the thermal losses of the two different types of networks, to pinpoint the magnitude and temporal occurrence of these losses and with that explore the energy efficiency potential of LTDHNs.

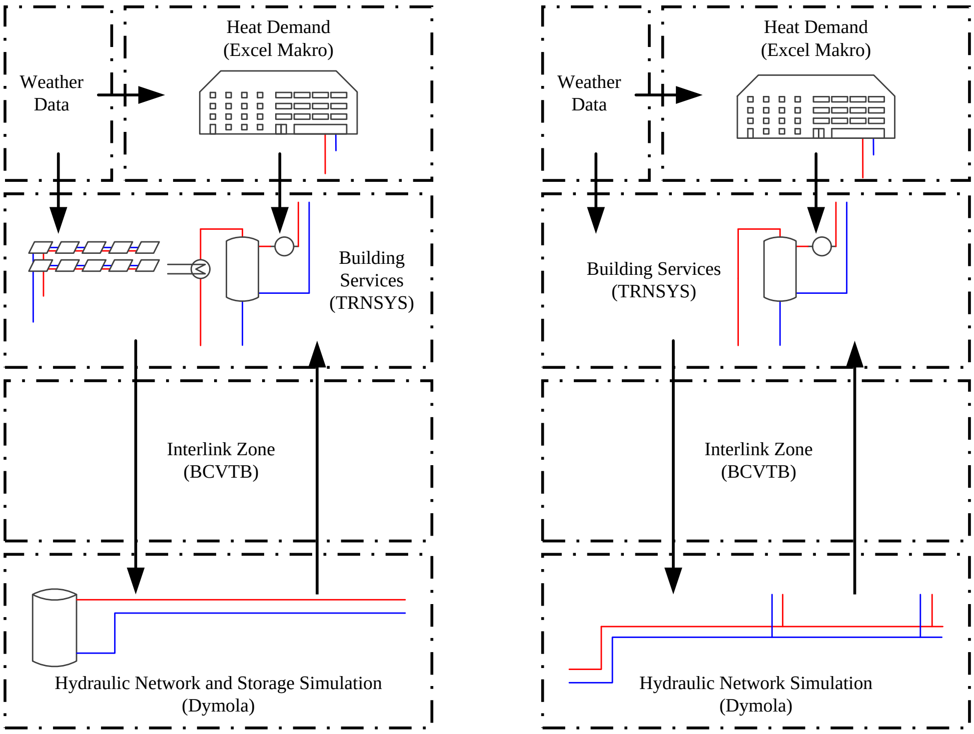

Figure 2. Model Frameworks (LTDHN left, DHN right)

The DHN and LTDHN frameworks shown in Figure 2 partially differ in the models they contain:

DHN framework

The **DHN Building Services Model** contains a small stand-by storage which feeds the heating water (HW) and the domestic hot water (DHW) loop (Figure 3):

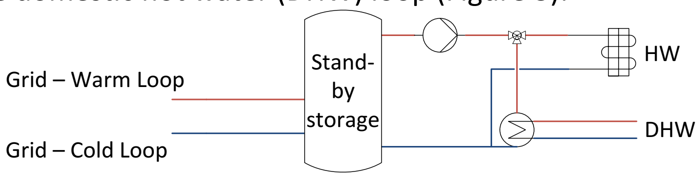

Figure 3. DHN Building Services Schematic

This storage is supplied by the **DHN Hydraulic Network Model**, a one-directional grid with fixed supply temperatures. To prevent cooling-down during times of low heat demand, supply and return line are periodically short-circuited (thermal flushing) to maintain a minimum supply temperature of 60°C in the outermost legs of the grid.

LTDHN framework

The main components of the **LTDHN Building Services Model** are the solar collectors, stand-by storage, buffer storage, heat pump and electric heater (Figure 4). The solar loop connects the collectors with the stand-by storage and the buffer storage. The stand-by storage is supplied by the solar loop or the secondary loop of the heat pump, and supplies the energy needed by the HW loop and the DHW loop, which is additionally heated by an electric heater. The heat pump is fed by the primary loop which connects buffer storage, heat pump and LTDHN. The aim of the LTDHN building services model is to maximize the local use of heat and use the LTDHN as overflow/source only when needed.

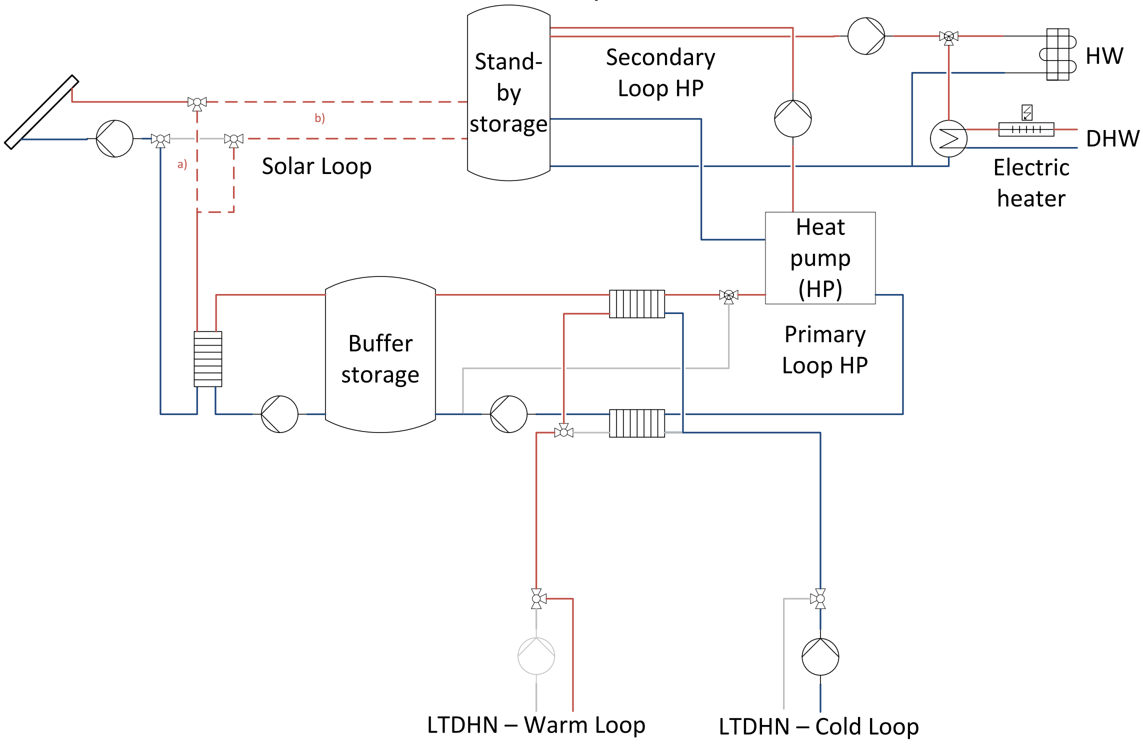

Figure 4. LTDHN Building Services Schematic

The main component of the LTDHN Hydraulic Network and Storage Model is a bidirectional grid which allows a reversal of flow within the grid depending on the applied loads and temperatures. A borehole heat exchanger acts as seasonal storage and ensures hydraulic balancing (Heissler et al., 2016).

Simulation

Both simulations are fed with identical load profiles which are based on a case study of an ecological model settlement quarter. The ecological model settlement quarter is part of a 30 hectare area, the site of the former Prince-Eugen-Barracks in the east of Munich, which is to contain up to 1800 flats and is currently under development (Opitzsch, 2014).

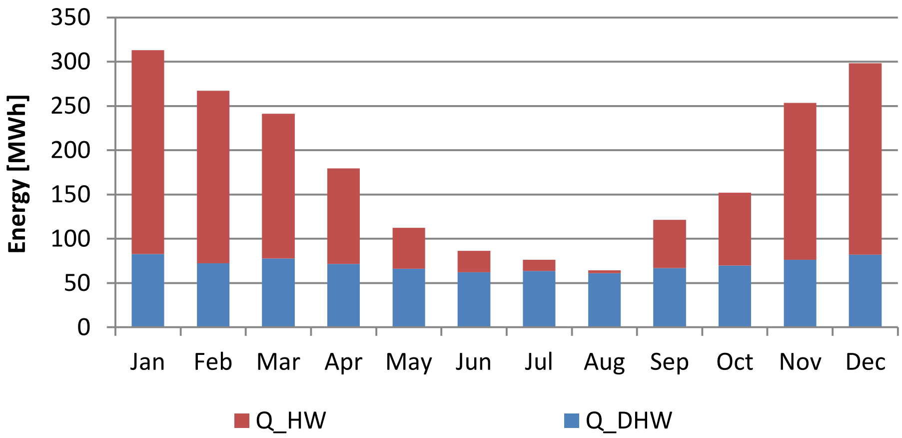

Figure 5. Monthly heat demand for HW and DHW production

The demand levels are calculated on the basis of DIN 4108-6 and are transformed into load profiles using VDI 4655. Figure 5 shows the cumulated monthly heat demand for HW (Q_HW) and DHW (Q_DHW) of the model settlement quarter.

The monthly heat demands add up to a total annual heat demand of 2175 MWh. Taking into account the transient process after initialisation, the results looked at are the results of the second year of a two-year simulation period. Table 1 shows the general simulation parameters:

Table 1. General simulation parameters

Parameter	*Value*
Total grid length	1830 m
Pipe insulation thickness	60 mm
Pipe insulation material	Polyurethane (0.03 W/mK)
Ground temperature level	2.2-13.8°C
Total annual heat demand	2175 MWh
Total heated floor space	53700 m²

The topology, length and architecture of the network models, the temperature level of the ground the pipes are installed in, the insulation thickness, the feed and tapping points of the connected buildings as well as the heated floor space are identical for both frameworks.

Results

Before comparing the thermal losses of the two networks, it is necessary to have a closer look at the boundary conditions which lead to these losses. Based on the supply temperatures of second generation DHNs of 100°C (Lund et al., 2014) and the topology at hand, as discussed earlier, average return temperatures of about 66°C are reached.

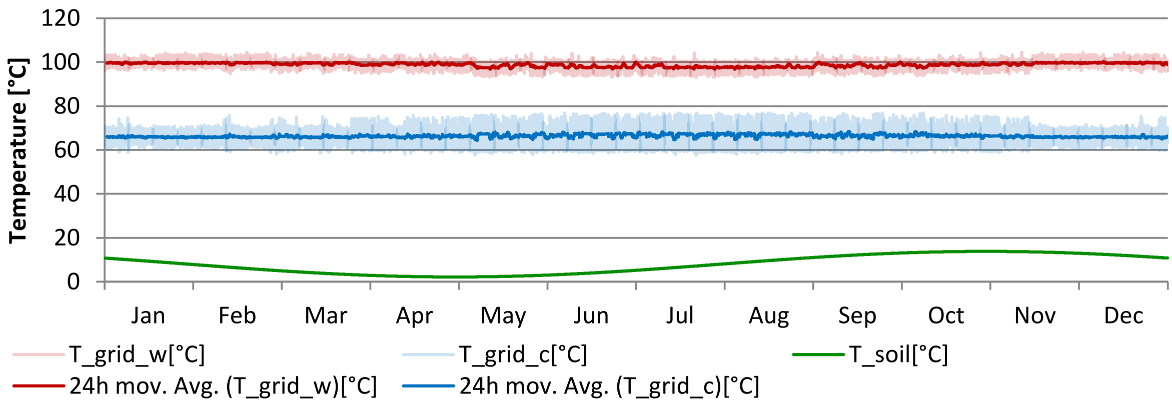

Figure 6. DHN temperatures of supply and return flow at the heat source.

Figure 6 depicts the temperature range in the supply (red) and return pipes (blue) of the DHN simulation obtained at the heat source. The bold red and blue lines show the 24 h moving average temperatures. In the background the highly dynamic hourly temperature values in light blue and light red are displayed. The supply temperature in the DHN does not change significantly over time. This reflects the ability of traditional heat sources in DHNs such as heating and combined heat and power (CHP) plants to adapt quickly to changing demand conditions.

The return temperature is not as evenly distributed, especially during the summer months. These are the months with the lowest heat demand (see Figure 5) which leads to stagnation and cooling-down of the fluid. The aforementioned periodic flushing to maintain a minimum supply temperature results in the temperature fluctuation depicted. The bold green line displays the undisturbed ground temperature over the course of one year.

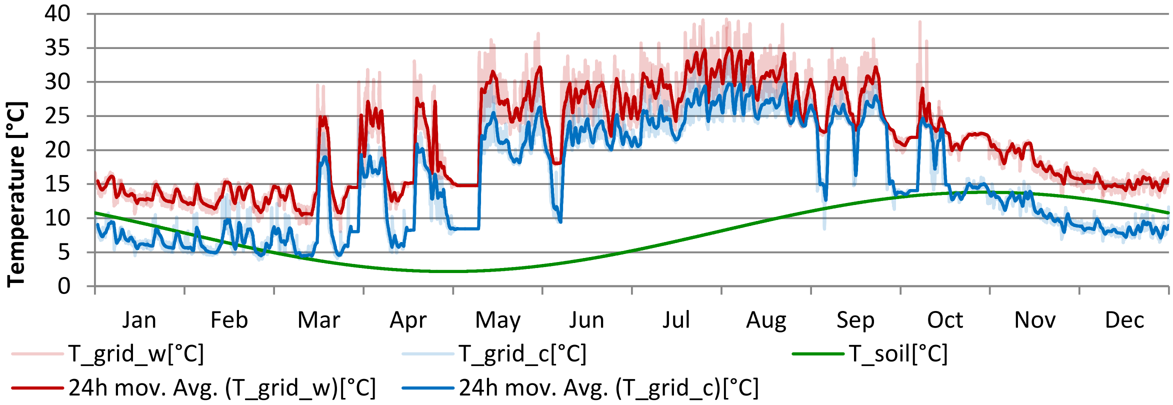

Figure 7. LTDHN temperatures of warm and cold leg connected to the seasonal storage.

Figure 7 depicts the temperatures of both warm and cold legs connecting the seasonal storage with the LTDHN. As before, the bold green line displays the undisturbed ground temperature. Compared with Figure 6 the absolute temperature levels and the temperature characteristics differ significantly. Here, they show a clear correlation between time of year and temperature level, as well as highly dynamic and fluctuating temperatures during the transitional seasons. Looking at the temperature differences between the fluid temperatures and the undisturbed ground temperature, the traditional DHN is operated with an average temperature difference of 74.6 K while the LTDHN operates with an average temperature difference of 10.2 K.

In the case of the DHN these temperature differences lead to a permanent flow of heat from the network to the surroundings. Figure 8 depicts the monthly thermal losses of the DHN. In total, these losses amount to 282 MWh per year, which is about 12.97 % of the total annual heat demand of the buildings.

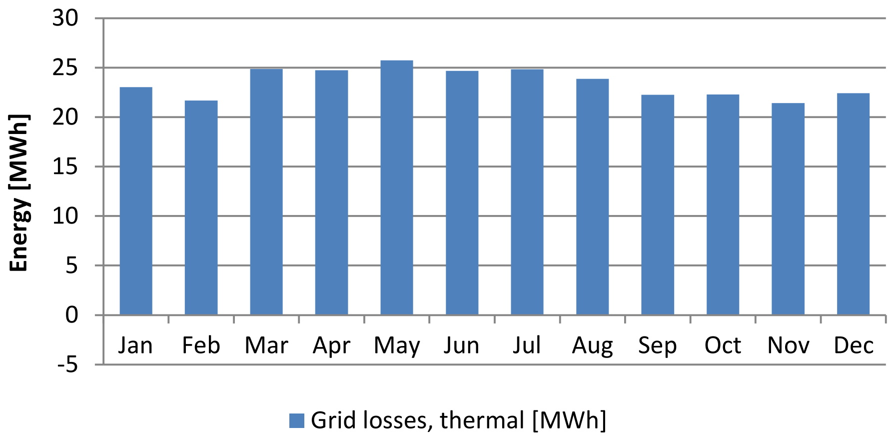

Figure 8. Thermal losses of the state-of-the-art DHN.

The losses of the LTDHN show a different annual distribution, correlating directly with the increasing temperature difference to the surroundings during the summer months

(Figure 9) due to high solar thermal collector gains. These losses amount to a total of 41 MWh per year, which is about 1.89 % of the total annual heat demand of the buildings. During the months December and January the average temperature level of the LTDHN drops below ground temperature resulting in negative losses, which are in fact heat gains.

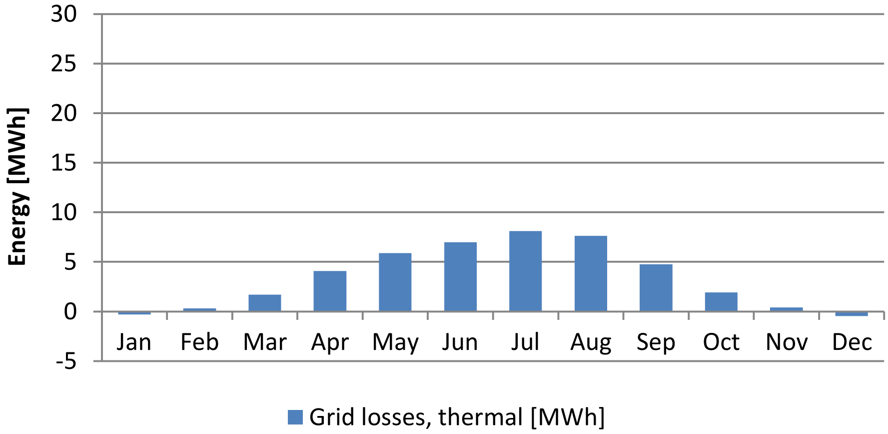

Figure 9. Thermal losses of the LTDHN.

The difference between the thermal losses of DHN and LTDHN amounts to 241 MWh per year, which is about as much energy as the model settlement quarter needs in the month of March for HW and DHW production.

Discussion and Conclusion

Comparing the calculated thermal losses of the DHN with the average losses of state-of-the-art DHNs in Germany of 13 % (Pfnür et al., 2016), a result of 12.97 % seems plausible. The simulation result of the LTDHN framework also quantifies the thermal losses of the LTDHN to about 1.89 % of the model settlement quarters total annual heat demand. This could potentially save 241 MWh of thermal energy every year, compared to the losses of the DHN.

With the above depicted temperature differences between supply and return lines of the DHN (32.5 K) and the LTDHN (5.9 K), we see that there has to be about 5.5 times the mass flow in the LTDHN compared to the traditional DHN to transport the same amount of heat. Therefore it is expected that additional electric energy has to be provided for the additional pumping capacities and heat pumps needed to operate a LTDHN. However, this does not account for heat pump gains, local solar gains or the prevention of thermal flushing, which could shift the ratio in favour of the LTDHN.

For the purpose of this study the ratio of renewable to non-renewable energy used by the system was neglected. Traditional DHNs are mostly powered by non-renewable fuels (BMUB, 2016) which makes the thermal losses of DHNs mostly non-renewable. LTDHNs on the other hand are largely powered by renewable energies, which lessens the impact of the few losses of a LTDHN further.

Further Research

Based on this result one of the directions of our future research will be the investigation into pumping power, heat pump power and pressure losses. Another focus will be a closer look at the potential of additional photovoltaic collectors as well as a comparison of different types of solar collectors in the LTDHN building services model. Future investigation could also include the effects of different types of seasonal storage and varying network layouts on the LTDHN.

Acknowledgement

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Design to Thrive

A Social Survey (2016-2017) on How the Economic Crisis Affects Peoples' Attitudes Towards the Environmental Subjects

Panos Kosmopoulos[1*], Athina Kantzioura, Ioannis Kosmopoulos, Konstantinos Kleskas, Andreas-Michael Kosmopoulos

[1] K-eco Projects co, f. Director of the Laboratory of Environmental and Energy Design of Buildings and Settlements, DUTH
[*] Corresponding author: E-mail: pkosmos@env.duth.gr

Abstract: This article presents a panhellenic social survey regarding Environmental subjects. It is a well known fact that Greece is suffering from an Economic Crisis among other E.U. countries. This crisis coincides with the time that Greece is supposed to take measures for Environmental Protection in general, that should aim both at Energy Saving, and at gaining energy from Renewable and Alternative Sources. During the last twelve years, we have conducted social surveys regarding people's attitudes towards the Environmental issues and the application of RES (Renewable Energy Sources) every two years. This research aims at the investigation of how peoples' attitudes and views towards the Environmental subjects and the use of RES. are affected by the Economic Crisis, and a rather dystopian general future. How serious and important are the environmental issues considered to be when people feel that their everyday life is threatened? This subject is approached through a panhellenic survey analyzing the data gathered by questionnaires. Within a framework of an international economic crisis, Hellas has been the first of the European countries that has been badly affected. But at the same time, according to the E.U. Directives, Hellas has to conform with the regulations regarding the application and the use of Renewable Energy Sources. It is very interesting to see how environmental matters are faced in general, regarding energy sources, fuels and related costs during this transitory period. But parallel to the above, Hellenic people have to face their household economics, their traditional attitudes towards their environment (both built and natural) and their dependence from imported fuels (oil and gas). It is at least an intriguing subject to see how people cope with the above mentioned circumstances.

Keywords: Energy, RES, Environment, social survey, Economic crisis

Introduction

After an extremely heavy winter for Greece (below 0^oC for twenty days, very rare for Greece) (Table 1) and within a framework of an international economic crisis, Hellas has been the first of the European countries that has been badly affected. But at the same time, according to the E.U. Directives, Hellas has to conform with the regulations regarding the application and the use of renewable Energy Sources.

The first level, according to the recent legislation, regards the application of R.E.S. (Renewable Energy Sources) and especially photovoltaics in buildings whether private or state, in order to achieve electricity production from the shelter of the buildings.

Table 1: Minimum Temperatures at several cities in Greece during Jan 2017 (http://meteosearch.meteo.gr/)

	Athens	Alexan-droupoli	Volos	Drama	Ioannina	Thessa-loniki	Kastoria	Kilkis	Larissa	Xanthi	Patra	Serres	Florina
6/1/2017	5,6	-2,9	0,1	-2,7	-3,4	-3,8	-7,9	7,9	-0,4	-2,1	4,6	-1,3	-11,1
7/1/2017	0,9	-7,9	-4,8	-7,3	-7,8	-7,3	-9,3	6,6	-5,4	-4,0	1,4	-6,8	-14,3
8/1/2017	-1,1	-11	-6,1	-10,3	-11,3	-8,4	-12,1	3,4	-7,6	-5,6	1,5	-10,3	-18,1
9/1/2017	-0,9	-6,8	-5,6	-7,7	-11,5	-5,3	-9,7	5,4	-7,6	-6,6	1,2	-6,4	-17,6
10/1/2017	-0,7	-4,3	-5,6	-6,2	-5,2	-5,1	-11,1	4,1	-9,7	-6,8	2,5	-6,6	-17,6
11/1/2017	1,9	-3	-4,8	-9,3	-4,6	-4,2	-12,6	2,4	-11,1	-3,1	4,6	-7,7	-17,6
12/1/2017	5,8	-3,6	-4,7	-10,3	-9,2	-5,7	-12,7	1,9	-9,2	-1,9	6,8	-12,6	-18,8
13/1/2017	2,9	-3,6	-2,3	-13,8	-10,4	-2,3	-10,8	-1,3	-12,7	-2,7	7,2	-12,2	-13,4
14/1/2017	6,7	4,5	3	-8,3	0,2	0,9	-0,1	-2,7	-5,3	2,6	10,2	-5,2	-1,7
15/1/2017	7,6	0,4	3,4	-6,2	-6,1	4,9	-3,2	1,4	-5,9	1,6	7,8	-3,7	-3,3
16/1/2017	7,2	0,8	2,3	0,4	0,3	3,7	-0,4	0,1	0,9	2,0	7,6	-1,4	-2,7
17/1/2017	7,1	3,8	3,2	1,6	1,2	3,8	-0,2	3	1,6	3,7	8,1	0,4	-1,6
18/1/2017	6,7	3,2	3,6	2,3	2,5	5,3	0,7	4,4	1,7	3,1	8,5	2,5	-0,4
19/1/2017	8,7	1,2	4,7	1,4	1,4	2,8	0,8	4,8	3,4	0,8	8,9	0,2	-0,5
20/1/2017	7,5	-2,4	5,5	0,5	-1,2	2,3	0,7	2	4,1	1,8	7,8	-0,9	-1,2
21/1/2017	6,2	-5	3,7	-1,5	-5,2	0,5	0,3	-0,3	1,6	-0,6	7,2	-3,7	-1,5
22/1/2017	5,7	-6,6	1,5	-4,7	-5,7	-0,8	-1,6	3,2	-0,4	-1,1	6,8	-4,2	-8,3
23/1/2017	6,3	0,2	5,1	-3,9	-1,3	0,6	-1,2	4,9	4,2	2,2	8,4	-4,8	-7,9
24/1/2017	7,4	0,2	4,7	0,6	1,7	3,3	0,3	5,5	4,2	3,4	9,2	-2,1	-3,2
25/1/2017	6,4	-0,4	4,5	1,1	0,8	2,2	0,5	6,7	3,8	0,7	8,8	1,9	-6,8
26/1/2017	4,4	-4	3,7	-4,2	-0,6	0,6	-2,4	6,3	1,8	-0,6	8,4	-2,6	-6,8
27/1/2017	3,4	-9,1	0,8	-7,5	-3,4	-0,6	-4,8	7,7	0,2	-2,7	6,4	-5,3	-12,3
28/1/2017	1,4	-3,7	-0,4	-6,4	-6,1	-1,8	-6,6	5,3	-1,9	-1,8	5,8	-6	-16,1
29/1/2017	5,7	-4,3	2,6	-1,3	-1,9	1,9	-3,7		0,3	-0,5	9	-1,6	-11,1
30/1/2017	4,9	1,8	4,1	1,4	-1,7	3,7	-0,3		3,8	1,8	8,5	1,8	-3,6
31/1/2017	5	-3,8	4,9	-2,7	-1	3,3	0,9		2,5	-0,2	6,8	1,3	-3,9

The second level, regards the installation of larger units of P.V. systems in land properties.

The third level, refers to the large scale installations, which aim at a national level of R.E.S. exploitation.

It is also interesting to see how environmental matters are faced in general, regarding energy sources, fuels and related costs during this transitory period.

The sensitivity of Hellenic people towards environmental matters is a well known fact: the traditional architecture, the antiquities, the natural environment and the related protective legislation, have established a concrete culture, which more or less, nowadays has to be denied. It is obvious that a new environmental aesthetics culture has to be shaped.

But parallel to the above, Hellenic people have to face their household economics, their traditional attitudes towards their environment (both built and natural) and their dependence from imported fuels (oil and gas).

It is at least an intriguing subject to see how people cope with the above mentioned circumstances.

Among other research projects, every two years, we conduct a social research regarding the attitudes of Hellenic people towards R.E.S. (see Kosmopoulos 2002/2004/2006/2008/2011/2013/2015).

The increasing interest regarding the R.E.S. applications and their benefit, has been well shown during the past years, and also the increasing level of familiarity with the related subjects has also been shown.

But at this instance, with the official legislation on one hand pressing for the use of R.E.S., and the economic crisis on the other hand, the present social survey seemed to be at least intriguing.

The research project

The survey has been planned and carried out by members of the K-ecoprojects co. and a large number of students, postgraduates, and PhDs that have attend our lectures.

A large number of areas and cities have been covered, offering a satisfactory image of the subject.

As for the subjects among the citizens, there has been a random selection covering the whole area of each city and its suburbs, all age groups, and several occupation and educational level groups.

The questionnaires gathered, have been processed by the staff and the collaborators of K-ecoprojects. The task has been to extract easily understandable data, in order to help the authorities that might be interested to use the results of our survey.

The questionnaire is based upon the Guttman scale (Canter, 1988) but it has been adapted to the well approved and generally accepted 5 point Likert scale, in order to be comparable to all previous relative study (see Kosmopoulos 2002 / 2004 / 2006 / 2008 / 2011 / 2013 / 2015).

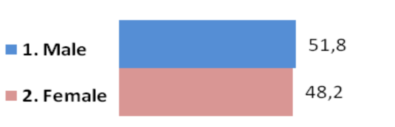
The survey

The research project, regarding the social attitudes towards the environmental subjects during this critical period, has lasted from 10/2016 to 3/2017, all over Hellas (and Cyprus) through the collection of questionnaires, and has covered the respective number of valid questionnaires:

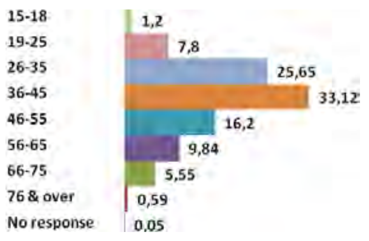
City	Quest.	City	Quest.	City	Quest.
AGRINIO	24	KAVALA	32	XANTHI	33
ATHINA	238	KALAMATA	23	ORESTIADA	15
ALEXANDROUPOLI	24	KARDITSA	25	PATRA	41
AMYNTAIO	16	KASTORIA	31	PEIRAIAS	38
VEROIA	26	KATERINI	17	RETHYMNO	15
VOLOS	45	KERKYRA	21	RODOS	17
GIANITSA	18	KILKIS	15	SERRES	41
GREVENA	27	KOZANI	33	SPARTI	19
DIDYMOTEICHO	14	KOMOTINI	41	TRIKALA	15
DRAMA	28	KORINTHIA	23	TRIPOLI	9
EDESSA	29	KOS	11	TYRNAVOS	11
IGOUMENITSA	22	LARISA	35	FLORINA	31
IRAKLEIO	38	LEFKADA	9	CHALKIDA	19
THESSALONIKI	202	MYTILINI	19	CHANIA	17
THIVA	23	NAFPLIO	15	CYPRUS	45
IOANNINA	22				
TOTAL: 1512					

The social survey results

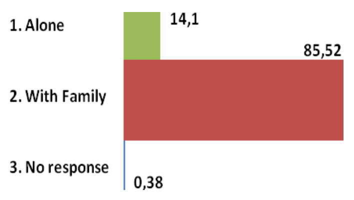
2. Sex



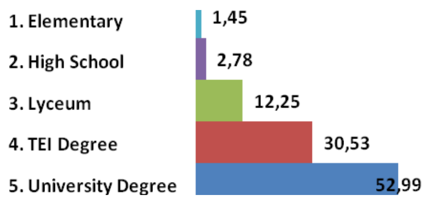
3. Age Groups



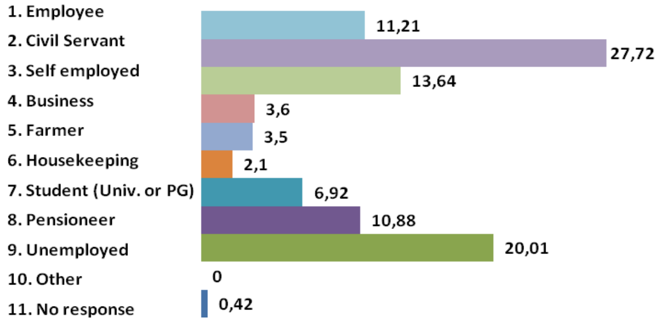
4. I live...



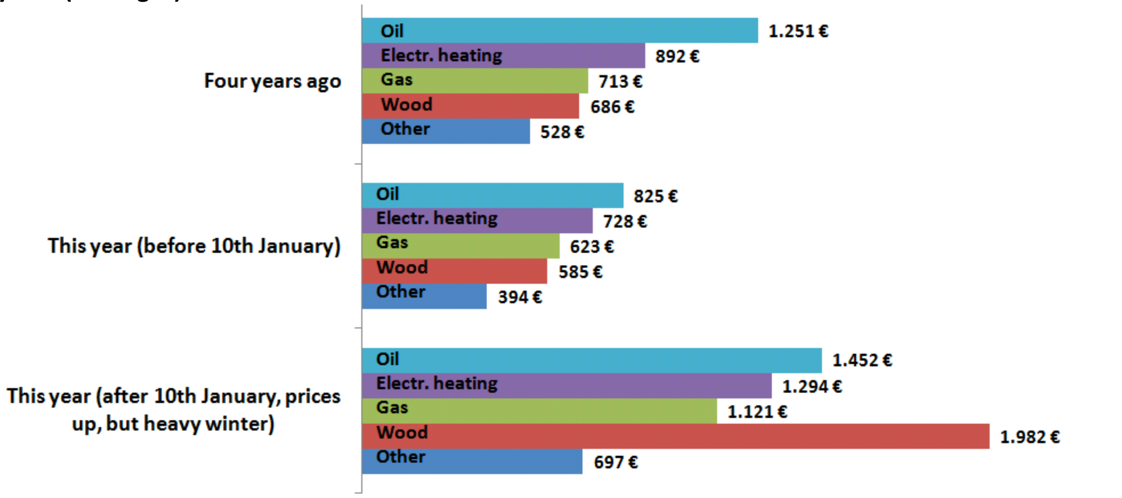
5. Educational level



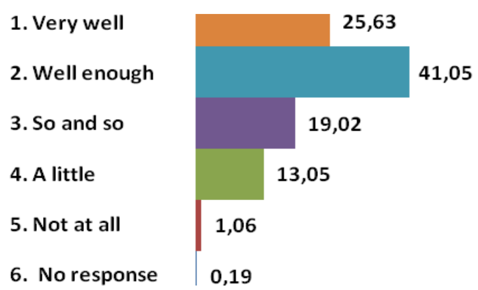
6. Occupation



7. How much money did you spent annually on various forms of energy, e.g four years ago and how much this year? (Averages)

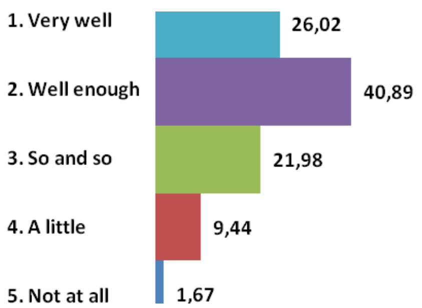


8. Do You know what Renewable Energy Sources are?

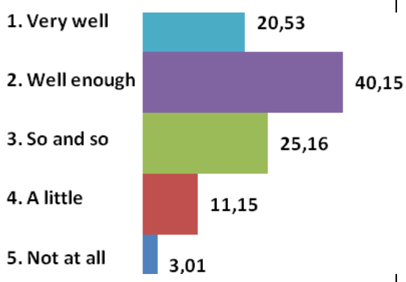


9. How well do you know about the following:

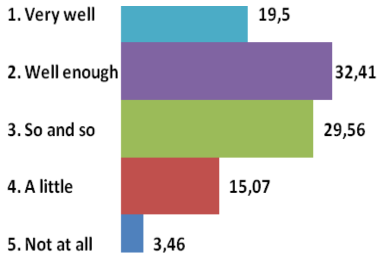
9.1 Photovoltaics in buildings:



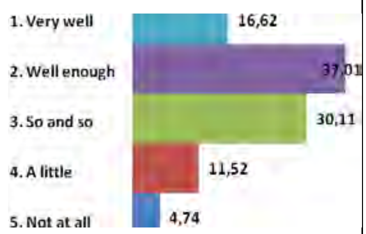
9.2 Photovoltaics in land properties:



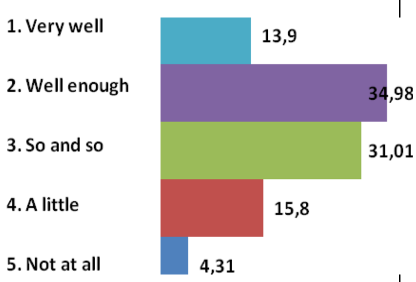
9.3 Photovoltaic Parks:



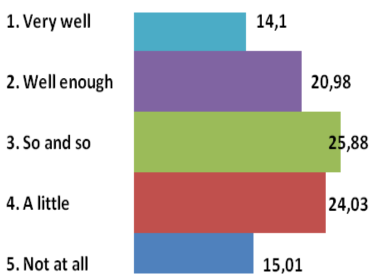
9.4 Wind Generators:



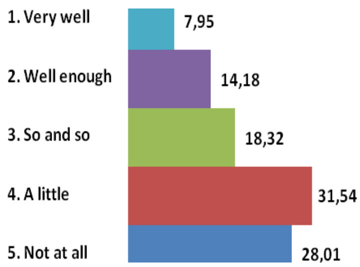
9.5 Wind Generators Parks:



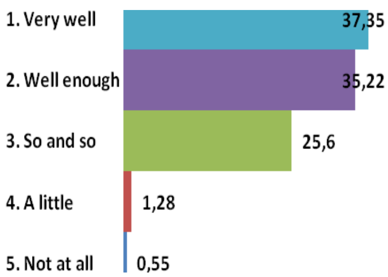
9.6 Geothermy for buildings:



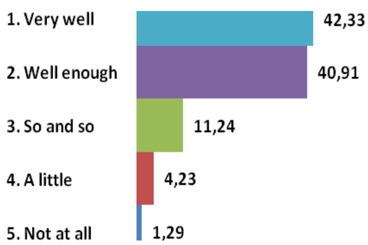
9.7 Geothermy for settlements:



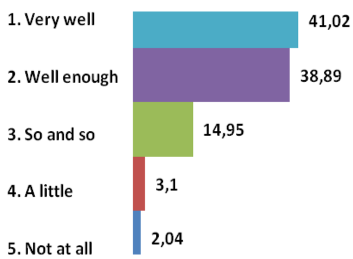
9.8 Biomass (wood blocks and pellets):



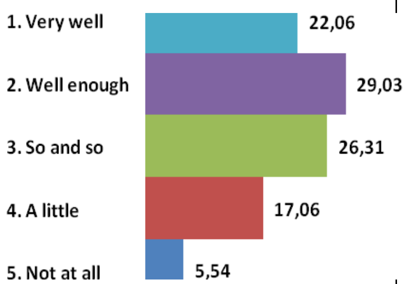
9.9 Double Glazing



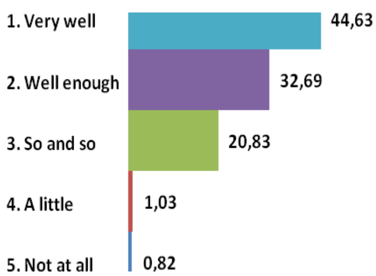
9.10 Insulation in walls



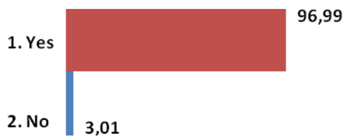
9.11 Glass House:



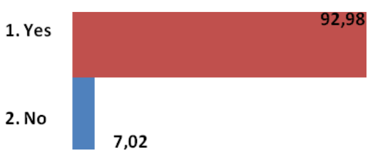
9.12 Fan:



10. Do you know that all of the above can help the family income?

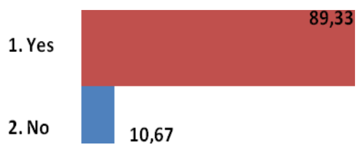


11. Do you know that all of the above can help our national economy to become independent from imported oil and natural gas?



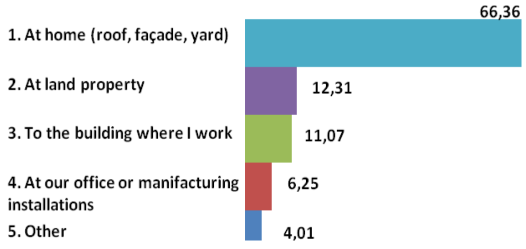
12. Do you know that all of the above can help to reduce environment pollution?

13. Do you already use any of the above?

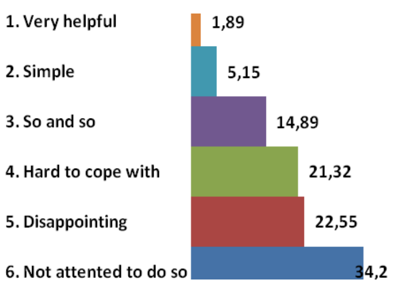


13.1 If yes, which one:

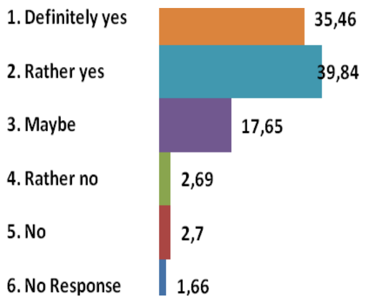
13.2 If no, would you like to install any of them:



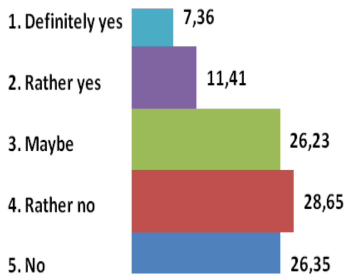
14. If you have already attempted to do so, what is your comment on the necessary beaurocracy?



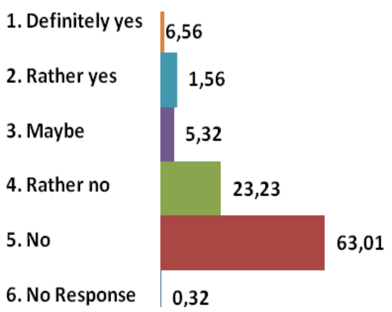
15. If you are reassured from the authorities that you will have definite economic gain, and a simple beaurocratic procedure, would you proceed to install any of the above?



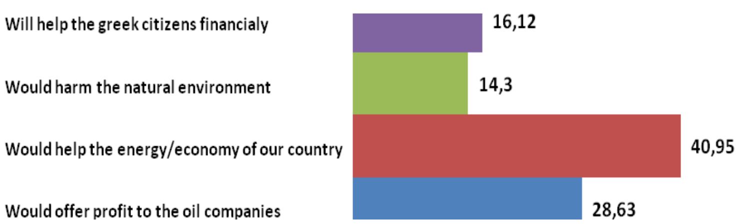
16. Do you think that the installation of P.V.S and W.G.S insult/destroy the aesthetics/natural beauty of buildings and/or the natural environment?



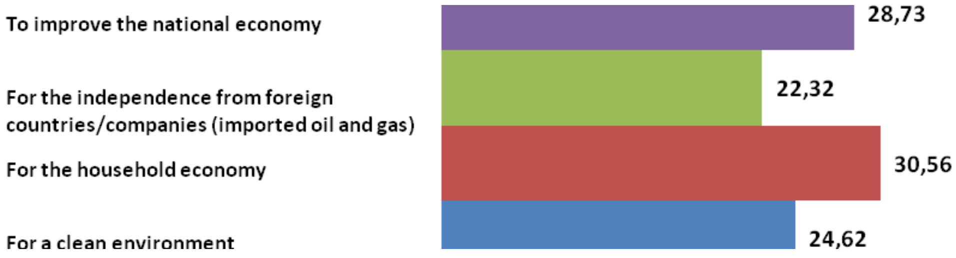
17. Would you accept a nuclear plant in our country?



18. We have learned that there are fossil fuels in our country. Do you think that their exploitation:



19. Finally, would you wish to see a wide use of R.E.S. for the following reasons:



Discussion and conclusions

The number of the participants to this research, and the answers that have been gathered, permit us to point out several subjects of interest.

1. Both male and female, and also all age groups, have been covered satisfactorily.

2. The educational level and also the occupation of the participants, have also been covered satisfactorily.

3. The cognitive level regarding Renewable Energy Sources, seems to have significally improved regarding our previous relative surveys . Both the general questions regarding R.E.S. and the specific questions regarding partial subjects such as PV, or WG, or parks to mention some, seem to be "well enough" known by the public.

4. For example, to the question about PVs the "well enough" level from 30,7% in 2011, in this research, it has reached 40,89%. And regarding PV parks, the "well enough" from 25.20% has reached 32,41%.

5. Regarding WGs, from 25,72% in 2011 we find now 37,01%, and in WG parks, from 22,40% today it has reached 34,98%. In conclusion, the campaign by the media seems to be achieving its aim.

6. Geothermy does not seem to be well known. Contrary to Biomass (wood blocks and pellets) that due to the high prices of oil and natural gas, seems to become very popular (from 17,99% to 72,57% !).

7. Regarding the economy point of view, several interesting remarks can be pointed out: Most people seem to have understood that R.E.S. can help both the family income and the national economy.

8. Among the people that already use some of R.E.S., Photovoltaics and especially Biomass are ahead.

9. People who would like to install R.E.S., are interested to do so firstly at home, and then to a farm or land property.

10. A very important point that has been underlined, is that since August 2012 a new laws have decreased the income from the installation of PVS, and it seems that this policy will continue. This legislation has a negative effect to the interest towards new installations of PVs.

11. Regarding bureaucracy, which seems to be a major problem in Greece, people seem to be disappointed, but in case the state should establish simple and clear rules and also some guaranteed economic gain for the citizens, R.E.S. applications should definitely increase.

12. Another interesting subject, is the change of the attitudes towards the aesthetics of the environment concerning the installation of R.E.S. all over the country. During two previous surveys (e.g. 2007,2009) people seemed to be firmly against large scale installations, arguing about the natural environment preservation. Nowadays, most people seem more interested in installing R.E.S. in their property, since 55,01% declare not to be disturbed by the PVs and/or W.Gs.

13. Regarding the possibility of the construction a nuclear plant station in Greece, people point out the seismic activity of the area and the danger of severe pollution, and seem to be definitely against such an idea (87,00%)

14. Recently, it has been known that in Greece there are large amounts of fossil fuels, oil and gas. Of course, people are not precisely informed, but anyway they consider that in case these fuels are exploited, firstly it would help the economy and the energy problem of this country, but also that it would offer profits to the (foreign) oil companies.

15. Finally it is interesting to see the general attitudes of the participants towards the wide use of R.E.S. firstly, for the protection of the environment, secondly for the improvement of the national economy, but also for the independence from imported fuels, and the less energy cost for each household, though the last recently seems to fade away.

16. Comparing the educational level of the participants with their views towards the environmental subjects, in brief we can observe that the higher the degree, the more they know about R.E.S., they are more reluctant to contribute financially to the state attempt for R.E.S. applications, they have faster been adapted to the idea of PVs and WGs around them, and that they also point out as their main interest, the need for the protection of the environment, through the use of R.E.S..

Concluding Remarks

1. Unfortunately, greek people have turned towards wood and oil for heating, due to the cold winter and the economic crisis.
2. Despite the economic crisis and a rather hard future, people seem to be well informed and very interested regarding the subject of R.E.S..
3. People are interested indeed for the protection of the environment, for the national economy, for the release from imported fuels, and finally for the personal/family economic profit from the application of R.E.S., but they are also disappointed from the new economic policy applied to R.E.S..

Acknowledgments

Many thanks are due to the members of K-eco projects co. and the students, postgraduates and PhDs, and most of all to the Greek people that have willingly participated to this research.

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System relevant Applications for Battery Storage Systems

Kurt Leonhartsberger[1], Marcus Meisel[2], Mario Pichler[3], Susanne Schidler[1], Lampros Fotiadis[2], Evangelia Xypolytou[2] and Andrea Werner[1]

[1] Department of Renewable Energy, University of Applied Sciences Technikum Wien, Vienna, Austria, kurt.leonhartsberger@technikum-wien.at;
[2] Institute of Computer Technology, TU Wien, Vienna, Austria, marcus.meisel@tuwien.ac.at@tuwien.ac.at
[3] Software Competence Center Hagenberg GmbH, Hagenberg, Austria, mario.pichler@scch.at

Abstract: By the end of 2015, more than 36,000 battery storage systems in combination with PV systems had been installed in Austria and Germany. As yet, these battery storage systems are mainly used to increase the on-site consumption of local PV generation. However, charging the battery without considering the current generation of the PV system and the current state of the grid means that this application is of little benefit for the grid, e. g. regarding control and stability, reliability, power quality or security. Alongside the use of battery storage systems to limit a PV system's maximum grid feed-in, several other grid and/or system-relevant applications for battery storage systems are possible. One strategy is to use autonomous systems to even out a building's load peaks, mainly caused by heat pumps or other electric heating or cooling systems. Forecast-based operation strategies are required. The research project Spin.OFF uses a self-learning artificial neural network (ANN) to predict the energy demand of buildings. In addition to local autonomous strategies, some system- and/or grid-relevant applications require coordination by third parties. The second strategy, presented in research project MBS+, provides a decentralized micro-grid concept for the optimization of Distributed Energy Resources (DER) in the form of a Battery-Storage-Network (BSN).

Keywords: battery storage systems, battery storage network, grid-relevant applications, artificial neural network, social implications

Introduction

By the end of 2015, more than 36,000 battery storage systems in combination with photovoltaic (PV) systems had been installed in Austria and Germany (Kairies et al, 2016). Investment subsidies and the desire of private households for energy self-sufficiency are the main drivers for this trend, which is most likely to continue to increase in the future. These systems are mainly used to maximise the on-site consumption of the local PV generation. However, charging the battery without considering the current generation of the PV system and the current state of the grid means that this application is of little benefit for the grid or the energy system (Weniger et al, 2016). Taking into account the public subsidies for such battery storage systems, it seems to be economically feasible to also use these battery systems within a defined scope for system- or grid-relevant applications, because the inter-connection of a rapidly increasing number of Distributed Energy Resources (DER) to the grid causes more and more problems of control and stability and also raises concerns about reliability, power quality, and security. One potential grid-relevant application is the use of these battery storage systems to even-out the PV system's grid feed-in. This application is mandatory in the German support programme for battery storage systems, where the maximum PV feed-in is limited to 50 % of the nominal PV power (since 2016) to ensure that PV peaks are always eliminated (Weniger et al, 2016).

System-relevant applications for decentralized autonomous energy storage systems

A grid-relevant application for battery storage systems is currently being investigated in a case study of an office building under construction in Vienna. The study implements an Aqueous Hybrid Ion (AHI™) battery storage system and answers questions concerning technical planning and dimensioning issues, ecological evaluation concerns, as well as its instrumental utilization to minimise power grid peak load or to maximise in-house consumption by means of an energy management system based on a self-learning artificial neural network approach (Maul et al, 2017). This section of the paper is concerned with first results of implementing and priming the energy management system with historical data from a comparable neighbouring office building.

In general, the energy consumption of office buildings can be divided into two parts. Tenant consumption, which is not a concern of this study, and the costs of operating the building, which are mainly caused by heat pumps or other electric heating or cooling systems, lighting, etc., but are also reduced by photovoltaic (PV) installations in the overall infrastructure of an office building. This mixture creates the need for energy management systems for the intelligent combination of resources, without changing the aim of evening-out load peaks and allowing for self-optimization. This case study implements a cradle-to-cradle certified battery implementation and 33 kW_{peak} PV system, reflects the scenario described above, and tries to answer all the issues arising in implementation. It also opens the possibility of retrieving data which can be used for further research. After installation, a tenant survey will be conducted to study the social impact and acceptance of this type of system. Lastly, an ecological analysis including a lifecycle assessment will be carried out to highlight the advantages of AHI™ battery storage systems and compare the result with other battery systems, such as Li-ion, Vanadium, Zinc-Iron and Redox Flow in terms of ecological footprint.

The energy management system was based on the use of a self-learning artificial neural network (ANN), not possible to realize with traditional grid-connected converters and their limitations in their applicability to dynamic systems, lack of processing power and missing interfaces. An ANN is a computational model made by a number of simple, highly interconnected processing elements, which process information by their dynamic state response to external inputs. It was developed as a self-learning feed-forward artificial neural network (FF-ANN) to predict power consumption (D'Andrea et al, 2012). An analysis of the electrical and architectural concept of the battery system was conducted within the technical and regulatory limitations. The performance of electrical security devices during isolated operation is being investigated to confirm that these devices respond accurately, since currently this is still uncertain. The energy management system implemented was primed with data from a comparable neighbouring building, and battery performance is currently being analysed to acquire new data regarding the energy flow, power ramps, power availability and power quality to gain insights into the physically achievable flexibilities offered by the new AHI™ battery storage system to create a model predictive control (MPC) system, as a second part, to manage the battery storage. The FF-ANN uses solar radiation, net energy consumption, building temperature data along with a day categorization system as inputs, the purpose of which is to predict short-term net building power consumption, hence the energy demand of the office building, and the MPC, based on the consumption forecast and PV production forecast, will create a charging/discharging schedule for the battery storage system.

Once installed in the office building, the system will be periodically retrained (the optimum frequency is yet to be determined) to include changes in the energy use behaviour of the building due to occupancy changes and various changes in the building structure, for example, more energy-efficient windows, or retrofitting more solar panels for increased local energy production.

The ANN model developed, presented in (Xypolytou et al, 2017), different input combinations were examined during the design of the FF-ANN. The parameters that affect the performance of the ANN are types of input and their pre-processing, the number of hidden layers used, the size of the hidden layers, the transfer function that creates non-linearity between the layers, and the time window that determines the samples used for the training. In addition, it is very important for the retraining period to be chosen in such a way as to allow adaptability to new conditions without affecting the performance of the FF-ANN.

The selection process of the inputs was based on various simulations and a comparison between architectures (see Figure 1). Mean Square Error (MSE) between target data and simulated data of the comparable office building was used as a benchmark (Tofallis, 2015).

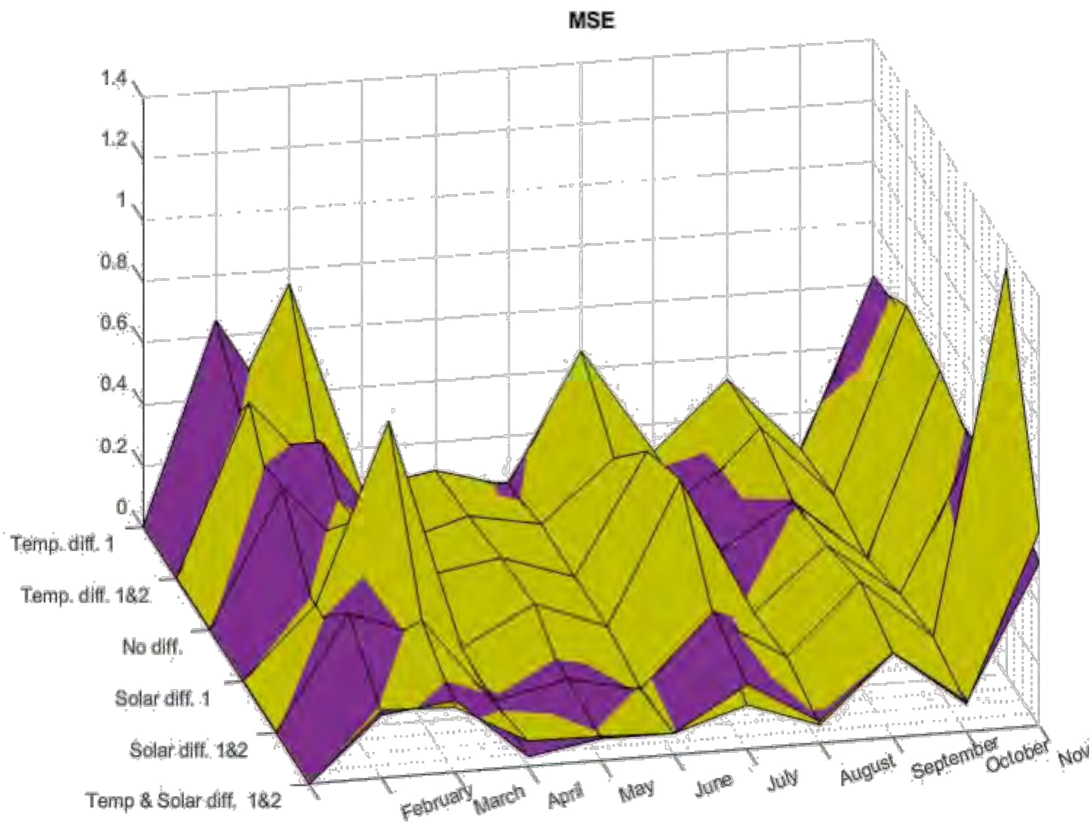

Figure 1. MSE comparison of 3 hidden layers (gold), size 7 neurons with 2 hidden layers and better performing (lower MSE) size 5 neurons (purple)

The current optimum set of inputs and pre-processing can be seen in Table 1.

Table 1. Input types and pre-processing

Input	Pre-processing / Type of input
Past energy consumption	Moving average of 4 hours
Solar radiation	Moving average of 1 hour
1st derivative of solar radiation	Moving average of 1 hour
2nd derivative of solar radiation	Moving average of 1 hour
Temperature	Moving average of 2 hours
1st derivative temperature	Moving average of 2 hours
2nd derivative temperature	Moving average of 2 hours
Date	Specific day of week, month, and holiday
Time	Hour of day

This FF-ANN consists of two hidden size 5 layers. The input layer has the 9 inputs shown in Table 1, while the output layer has size 1, which is the moving average of the next 4 hours. Each neural network layer has an integrated weight matrix (W) and bias vector (b). The transfer function of the hidden layers is the hyperbolic tangent sigmoid transfer function (tansig). The output layer is driven in a Log-sigmoid transfer function (logsig). The training time window used was 23 days. The Matlab® graphical representation of the current form of FF-ANN is shown in Figure 2:

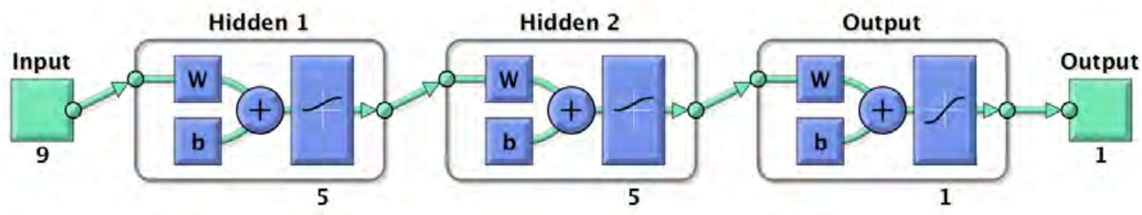

Figure 2. The current FF-ANN architecture in Matlab®

The power consumption projected by the FF-ANN and the actual consumption available in the historical test set is shown in Figure 3 below:

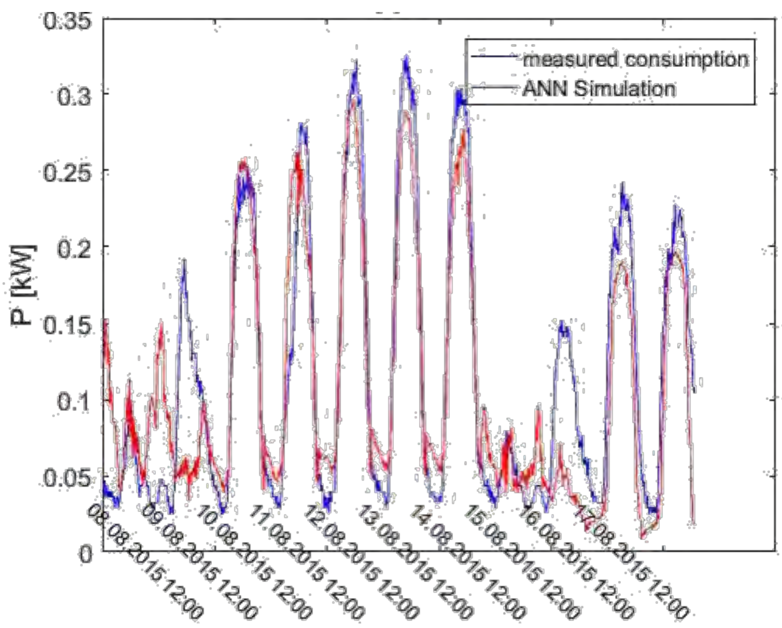

Figure 3. FF-ANN results on an exemplary 10-days test set

The system reflects choices made to create an FF-ANN the purpose of which is to predict the consumption of a building. It has the ability to be re-trained periodically. To achieve this, a local data storage will be integrated to save historical data. These data are a valuable source for the conduct of future studies which can further optimize local controllers.

Technical implementation

The technical approach involves connecting single battery storages (located in different households) to form a BSN. While these storages are connected to the power line, an additional communication network is required to enable these distributed storages to communicate and exchange information with each other.

To date, no or only limited support is available for collaboration among participants of a balancing group to utilize distributed storage devices for balancing generation schedule deviations. In particular, owners of PV systems and (private) battery storages are not able, e.g., to autonomously and jointly decide how to fulfil the requests of a balancing group officer (BGO) by using their aggregated battery storage potential.

Several approaches are considered feasible for fulfilling the given requirements of a decentralized BSN. Among them, peer-to-peer (P2P) technology (Oram, 2001; Fattah, 2002) represents quite an obvious choice. It is not only the notion of a computing architecture that does not rely on a central (server) component that makes P2P systems feasible for the envisaged BSN. In fact, there is an analogy between early P2P computing systems and the current discussion on the use of private and distributed PV systems and battery storages in a P2P manner. According to (Shirky, 2001), P2P applications take advantage of previously unused resources – storage, computing cycles etc. –, which allows them to make new, powerful use of a large number of devices that have been connected to the Internet. It is similar with the distributed components in the energy domain, like battery storages, PV systems, electric cars etc.

In addition to P2P systems, studies of multiagent systems (MAS), e.g. (Shoham and Leyton-Brown, 2009), have investigated concepts with specific relevance for BSNs. With MAS, autonomous (network) entities are called agents. In our BSN, single participating households or household devices are modelled as agents. These households, or even the battery storages in the households, regularly communicate their potential utilization at 15-minute intervals to their BGO. With this information in mind, the BGO then requests the whole BSN to provide/consume a specific part of this potential to/from the grid to keep the group balanced. At this point, the BSN participants jointly decide how to fulfil this request through distributed consensus finding. MAS provide a number of algorithmic options for the BSN participants, e.g. distributed constraint optimization, negotiation, auctions, voting or mechanism design.

A further, nascent technology – called blockchain – represents an apparent symbiosis of P2P and MAS technologies, and is currently gaining in importance in the energy domain (EventHorizon, 2017). A blockchain network represents a P2P network with a distributed consensus algorithm at its core. Additionally, through the abstraction of 'smart contracts', network participants are able to cooperate as is the case with MAS. Therefore, we are investigating the potential of blockchain as technology base for the envisaged decentralized BSN or if it is necessary to stick to more mature technologies.

A key constraint is the identification of a suitable solution for integrating the BSN-algorithms into – existing – household's energy or home automation system components. Hence, technologies that allow for the simple deployment of the developed BSN algorithms to these energy system devices are also part of the solution concept. In this aspect, container technologies like (Docker, 2017) and especially (Docker Swarm, 2017) for the realization of a reliable decentralized solution are complementing the concept.

Social implications

Especially if grid and/or system relevant applications require active coordination by third parties e. g. balance group managers or grid operators, one crucial aspect for the successful implementation and operation of such a BSN is the willingness and acceptance of storage operators (particularly private owners) to give access to external stakeholders. In order to assess this willingness of current and potential operators of home storage systems to participate in such a BSN, an online survey has been conducted. This assessment should serve as a proxy for the social implications of a BSN for system and/or grid-relevant applications.

The survey form contains up to 8 mainly closed-ended questions focussing on social aspects like motivation, risks, opportunities, framework conditions and incentives, as well as additional demographic and technical questions. With the support of the Vienna and Styria funding agencies [1] as well as of the national "Climate and Energy Fund", the survey was distributed to about 20,000 operators of home storage systems and/or a PV system.

Within 3 weeks, the survey had been completed by about 2,300 respondents, of whom 257 PV operators already owned a battery storage system. This meant that about 11 % of the PV owners originally contacted were included in the study sample. The data were analysed mainly using descriptive statistical analysis using Excel and SPSS.

The results of the survey show a high willingness of PV operators (with or without a battery storage system) to participate in a BSN for system and/or grid-relevant applications, although subject to certain conditions. While only 10 % of the sample would participate without further conditions, almost 75 % would agree to participate only under certain framework conditions. This result emphasizes that the development of these framework conditions is a crucial factor for the success of such a network.

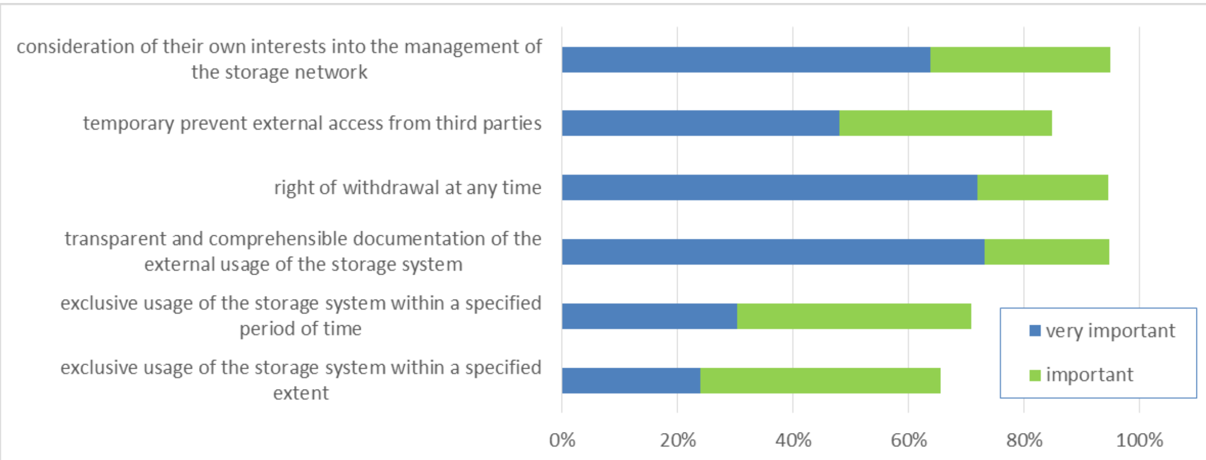

Figure 4. Importance of selected potential framework condition for the participation in a grid- and/or system-relevant BSN

Those 85 % of the sample who stated that they were basically willing to participate (even though only under certain framework conditions) were asked about the importance of selected framework conditions, their motivation and possible (financial) consequences regarding a potential participation. As displayed in Figure 4, the right to withdraw at any time,

[1] Vienna: Municipal Department 20 - Energy Planning, Styria: Department 15 Energy, Housing, Technology

as well as a transparent and comprehensive documentation of the use of the storage system were ranked by a majority of respondents as ‘very important’ (72.01 % and 73.12 %) conditions, shortly followed by their own interests being considered in the management of the storage network (63.74 %). Asked about their motivation to participate, top-ranked answers were the contribution to ‘increased security of supply’ (42.65 %), and ‘a higher share of renewable energy in the overall system’ (40.62 %). In contrast, additional earnings opportunities were considered to be ‘very important’ by only one quarter of the respondents (25.71 %).

The study also gives insights into the relevance and suitability of different incentives and financial compensation for the additional use of their own storage systems and the associated (financial) impacts on the owner. Regarding additional incentives for participation, 80 % of respondents seem to consider financial compensation for additional costs or foregone revenues to be sufficient for participating in such a BSN. This confirms that financial interests are not a decisive factor for participation. This is particularly interesting in contrast to the responses of battery storage owners’ statements about their initial motivators when buying the storage, in which ‘improvements in the profitability of their PV’ plant was stated by 97.5 % to be ‘very important’. Further analysis will therefore focus on the differences and similarities of respondents with and without their own battery storage.

Conclusions

Beside the usage of battery storage systems to limit the maximum grid feed-in of a PV system, several additional grid- and/or system-relevant applications for battery storages are available.

A case study of the impact of using a decentralized autonomous energy storage system, utilizing only local data for training a neuronal network as consumption forecast input, will provide more data to allow a better consumption prediction of wider application areas (residential, industry, different geographical areas, etc.). The objective of the system so far is to improve the coordination of system planning and to even out load peaks. A more advanced system could be designed to allow multiple objectives or to work on multiple buildings. A different objective could be to provide additional services such as trading between buildings in a micro-grid, or emergency functionalities to always allow building evacuation or energy redundancy for safety critical systems. A future integration in building management or smart home systems, an industry which has been progressing substantially in the last decade, can be considered very likely. The rapid advancements of both software and hardware solutions specialized in machine learning in recent years allow faster training of small neural networks. Although the development of self-learning systems able to predict energy demand is still a challenge, it is now computationally feasible to create a self-learning system on cheap off-the-shelf hardware. Cloud-based high-performance computing enables multiple models to be created in parallel, in which parameters of the models can be optimized with various methods (Grzesiak et al, 2007) (Goodfellow et al, 2014) in feasible time windows. This allows more generic systems to be designed, dynamically optimizing the parameters in parallel with the flow of new data. Available data for research is the biggest limitation for the use of deep learning techniques in energy consumption estimation (Mocanu et al, 2016).

Especially if grid- and/or system-relevant applications require active coordination and external access to the home storage system by third parties, one crucial aspect for the successful implementation and operation of a BSN is the willingness of storage operators to participate. In this context, the results of the survey show promising prospects for the successful implementation of a BSN for system- or grid-relevant applications. In total, almost

85 % of the sample would agree to participate, even though the majority only under certain framework conditions. Furthermore, the results emphasize the importance of transparent and comprehensible framework conditions and well-designed instruments for its implementation and management from the operators' perspective. Participation is predominantly ideologically and technically motivated (contribution to the energy transition and to a high supply service), financial aspects only play a minor role. Further analysis will discuss the results of the survey in relation to relevant framing conditions, as well as potential bias within the sample due to characteristics of the participants as 'early adopters' in the study, or effects of social desirability in their response behaviour.

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Design to Thrive

Engineering applications of solar energy – the most potent renewable resource

Professor Tariq Muneer

Edinburgh Napier University (ENU), Edinburgh, UK

Abstract: Solar radiation is the most potent renewable energy resource. The amount of radiation striking the earth on an annual basis is equivalent to 15,000 times that of current global energy consumption. Although photosynthetic energy capture is estimated to be ten times that of global annual energy consumption, only a small part of this solar radiation is used for photosynthesis. In contrast engineering applications of solar energy offer significantly higher efficiencies, i.e. for thermal applications the efficiency may easily exceed 50% mark while for solar photovoltaics an efficiency of over 15% is possible. This article will cover the six areas of research and application of solar energy. The research was undertaken at Edinburgh Napier University (ENU).

Keywords: Solar radiation, renewable, enginnering

Introduction

The design and modelling of solar energy applications demand (a) an accurate assessment of the incident solar radiation which will vary in a diurnal and well as annual cycle, and (b) an understanding of the physical processes that are encountered in solar energy exploitation systems. This article shall present the two of the above constituent elements. Under the ‘application’ strand four low-carbon technologies are presently included and relevant examples are also presented.

Solar radiation data

Solar radiation data are essential for the design of solar energy exploitation systems. In response to the above demand posed by industry, CIBSE (2015) has provided hourly time series of global and diffuse irradiation and illuminance data for 14 UK locations. The author served as the co-ordinator fo the latter activity and a synopsis of the relevant procedures is provided here for the benefit of the reader who may extend this work for other global locations.

For any given country the most commonly available measured solar data are the horizontally measured global radiation. These are available for a limited number of locations and that too at a significant cost. From an early work of Cowley (1978) we note that the solar radiation regime can change significantly over a distance of just 50km. However, through the work of NASA (http://eosweb.larc.nasa.gov/cgi-bin/sse/retscreen.cgi?email¼rets@nrcan.gc.ca) it is now possible to obtain daily-averaged irradiation data for virtually any location in the world. The author’s research team has undertaken an accuracy assessment of the NASA’s satellite-based data which is shown in Figure 1. The latter plot is based on measured data for the period 1981–1983 (three complete years) for a location that is in near proximity to West London. The statistics within the latter figure shows that there is a close concordance between the satellite-based NASA irradiation and the UK Meteorological Office measured data set. Figure 2 presents the computational chain that is required to obtain components of solar radiation and illuminance. Algorithmic details are provided in Muneer et al (2014, 2015) and Muneer (2004).

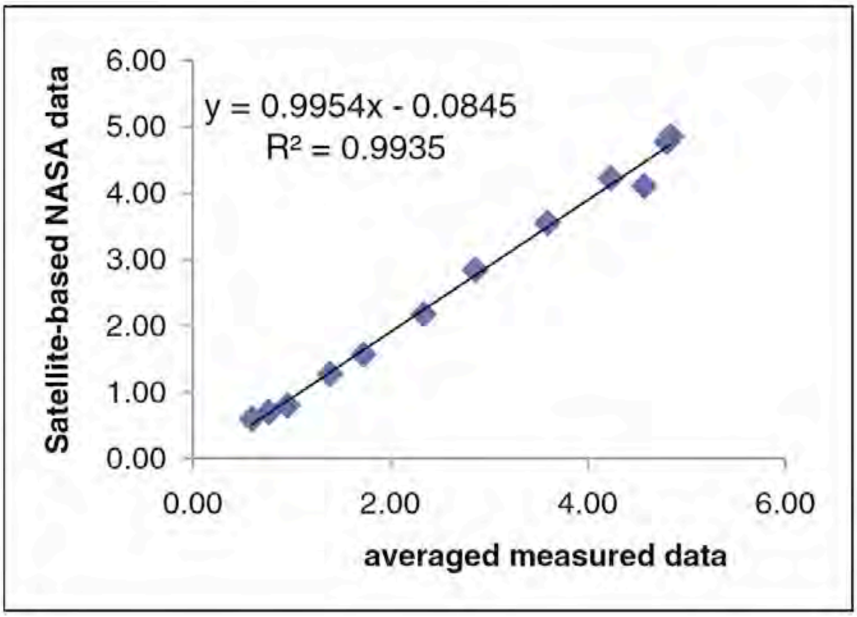

Figure 1. Comparison between NASA reported irradiation data and ground-based averaged measured data for Bracknell, England.

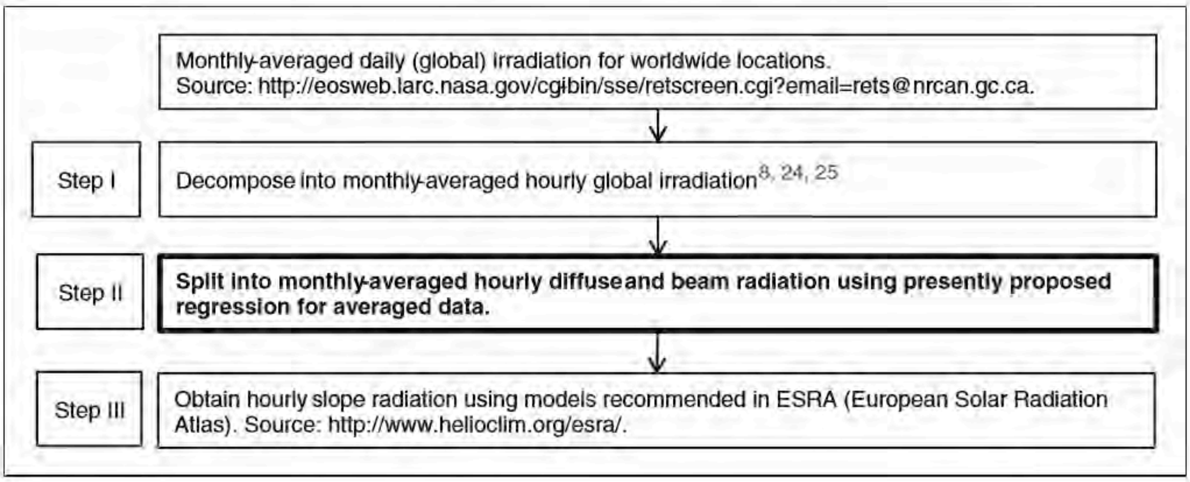

Figure 2. Computational chain for obtaining secondary solar data

Solar space heating

Buildings in the western world typically use–up at least 50% of the national energy budget and at least three-fifths of that is needed for space heating. A further fifth is needed for heating water. The key to space heating efficiency, capture and use of incident solar gains has long been identified to be high-performance glazing. Within the last 40 years we have seen the single-glazed windows with a loss-coefficient, U of 5.7W/m^2-K drop to 0.4 of the latter units for triple-glazed, Xenon-filled units. A factor 14 reduction! To prove a point in the year 1994 a solar conservatory was built at Edinburgh Napier University and its performance is shown in Figure 3. If the exterior surface of new-build is cladded with the latter units it will remove nearly all space heating demand for the majority of high-latitude locations.

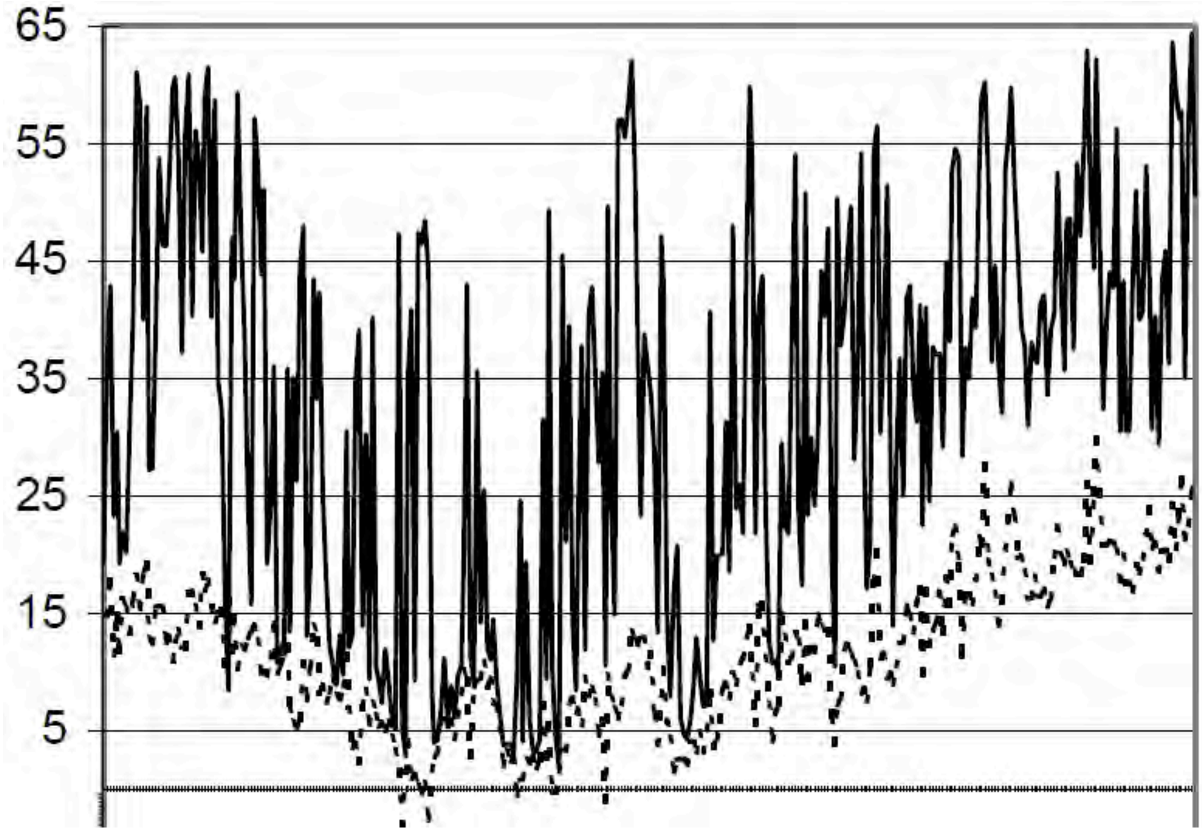

Figure 3. Annual performance of a solar conservatory using super-insulated glazing, Edinburgh. The heating season in the UK typically lasts between 9 to 10 months and this rather extended period works in the favour of solar energy economics due to the high utilisation factor. The super-insulated solar conservatory was built in August 1995 by Nor-Dan on a design produced at Napier University. At the heart of this design is a high performance triple-glazed window that acts as a thermal diode, i.e. the window admits solar energy into the sun-space but restricts the leakage of outgoing heat. Two window designs, both using specially coated low-emissivity glass have been tested. Hourly temperature profile using Argon-filled glazing is shown. The respective energy loss indices (centre-glazing U-value, W/m2-K) of the above mentioned windows are 0.73 and 0.4. These indices are in sharp contrast to the U-value of a normal double glazed window that lie around 2.8W/m2-K. Shown here are maximum daily temperatures (Celsius): solid line (sun-space), dashed line (outside ambient).

In the latter context following the earlier work of Owen (1982), and using Eq. 1 Table 1 has been prepared for Edinburgh. Note that the effective U-value takes into account the thermal balance which includes the irradiance as well as the outward heat loss from any given glazing.

$$U_{effective} = U - [1000 f_u \, \tau \, F_d \, I_w / (24HDD)] \quad (1)$$

Where f_u is the utilisation factor (= 0.6), τ the window transmission, F_d the dirt factor (= 0.8), I_w average irradiance (W/m2) and HDD the heating degree-days.

Table 1 Effective U-value for Edinburgh. Heating season: Sept – May (Heating Degree-Days = 2500)

Glazing	U-value	U-effective East/West	U-effective South
Single	5.7	3.9	2.6
Double: low-emissivity with air in-fill	1.8	0.3	-0.7
Double: low-emissivity with Ar in-fill	1.2	-0.3	-1.3
Triple: low-emissivity with Ar in-fill	0.7	-0.4	-1.1
Triple: low-emissivity with Xe in-fill	0.4	-0.7	-1.4

Solar water heating

In the western world hot water demand consumes some quarter of all energy used in buildings. Within the developing countries, though hot water demand is considerably less within buildings the latter saving is over-compensated due to the needs of the industrial sector. One area of rapid growth has been the textile industry which has seen an exponential rise within countries such as China, India, Indonesia, Pakistan and Turkey. The main use of water heating systems is for dying processes and currently the demand met with the use of fossil fuels. Within Pakistan's textile industry, which offers good employment prospects it is certainly the case. Pakistan's and Turkish solar climate can handsomely contribute towards the latter duty though to good effect. The author had the occasion to work with the textile industry of the two latterly mentioned countries (Muneer et al, 2006 and Asif et al, 2007) and a synopsis of that experimental work is presented here. Two different designs of built-in storage water heater - plain and a newly designed finned type heater were constructed to compare their thermal performance. One year's experimental data were collected for the two heaters. Figure 4 and Table 2 present those results.

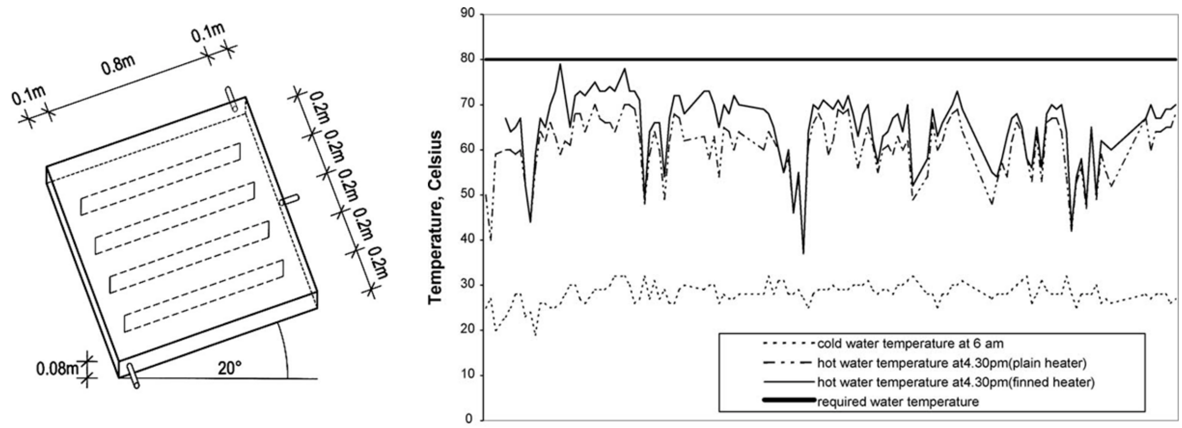

Figure 4 Isometric view of finned, solar water heater (left) and its daily performance to meet the 80^{o}C hot water demand required to wash cotton looms in textile industry.

Table 2 Comparison of Stainless steel (SS) and Aluminium (Al) solar water heaters (unit square meter frontal area)

	SS	Al
Annual-averaged temperature lift, Celsius	32.9	39.2
Life-time energy output, 20 years (MWh)	16.5	21.3
Thermal efficiency, %	47	61
Carbon payback, years	<1	<1
Economic payback, years. Fuel = gas	9	3

The technology under discussion is one of the most potent examples of what can be done with immediate effect to decline the release of greenhouse gases to atmosphere. The fabrication is low-tech, ideally suited for developing countries which also has a quick payback time in monetary and embodied energy terms.

Solar photovoltaic

In year 2015 the world electricity consumption was 21.7 Trillion kWh. This is equivalent to a constant load of 2.5TW. Between the years 1970 and 2014 the global-averaged per capita electricity usage had increased from 1,200 to 3,144kWh, a per-annum increase of 162%. This phenomenal growth will continue to rise with the advent of electric vehicles which are now being incentivised by governments as an instrument to combat kerb-side pollution. In terms of greenhouse gas emissions the latter will only be sustainable provided the renewable-sources based electricity increasingly displaces its fossil-fuel counterpart. Towards that end we note:

- Presently, 23% of world electricity comes from renewable sources.
- The cumulative wind power installed capacity at the end of year 2015 was 433GW.
- Likewise, solar PV capacity now stands around 368GW.
- The annual-averaged capacity factor for solar and wind energy are at best around 14- and 20%.
- The price drop per Watt of solar PV has been USD 7667 to 49 US cents in 40 years, a factor of 156.
- Likewise, the price drop for wind power has dropped by a third during the last four years to £97/MWh [Financial Times (2017)].
- Scotland is on track to generate 82% of its electricity from renewable sources by the year 2022.
- Globally speaking, by year 2050 solar energy is expected to become the largest source with PV and Concentrated Solar Power (CSP) respectively providing 16% and 11% global electricity. Likewise, wind power is expected to carry a 17% share thus making a total wind-solar contribution of 44%.
- Several years' worth of solar PV and roof-top wind turbine research was undertaken at author's own institution (ENU). Figure 5 shows the PV installations at ENU. With the price of solar and wind fast approaching the levelised cost of electricity (LCOE) the main question will be the payback period for embodied energy. Table 3 presents the analysis that was undertaken for ENU PV installation and reported in Muneer et al (2007). Despite contrary claims it was found that even with a predominant overcast solar climate the payback period for PV in Edinburgh was only 8 years. With a 20-25 year life for PV modules it is likely that the PV technology will payback its embodied energy 2.5 to 3 times over.

Sustainable transport

Transport represents a crucial sector in today's economy and society, having a large impact on growth and employment. From a societal point of view, the importance of leisure and its related activities in modern societies makes transport an essential activity for the normal development of human relations.

Table 3 LCA for the Edinburgh Napier University 15kWp PV installation

Thermal energy audit		Embodied	CO2
Element/Material	Mass, kg	energy MWh-th	released kg
Total spigots, Steel	200	3.3	440
Total vert. rails, Steel	2000	33	4400
Total tie brace, Steel	250	4.2	570
Total horiz. rails, Steel	500	8.4	1100
Total PV mod., Mixed	1500	180	3500
Cables, Copper	150	2.8	760
TOTAL		230	11000

Electrical energy audit		Embodied	CO2
Element	Mass, kg	energy MWhe	released kg
Inverters (2 IG60) Mixed	40	2	1700
Inverters (2 IG20) Mixed	24	1	700
Operation		2	1100
TOTAL		5	3500

Table 4 Energy, Environmental and Monetary economics for an electric vehicle

Energy used (kWh/km)	0.164
Energy used (kWh/mile)	0.262
Monetary economics	**pence/mile**
Electricity cost	3.15
Battery cost	0.78
Servicing cost	0.04
Vehicle depreciation cost	33.16
Total economic cost	37.12
CO2-emissions	**g/mile**
Charging based on UK grid	142
Charging based on Solar PV	12
Charging based on Nuclear, Hydro and Wind	3.3

Means of transport have evolved a great deal over time. The use of cars has become widespread in view of multiple advantages they offer. Amongst all means of transport, the car is considered the most convenient. The use of the car is flexible, is fast and agile and seems to be the only means of transport able to connect quickly with different locations, when offices, shops, hospitals, schools or sport facilities are far away from homes. In terms of safety, which is a top concern, driving a car makes us feel safer than for example driving a motorcycle, cycling or walking. A car is a solid and robust object that gives protection to drivers and passengers in car crashes and can withstand impacts. Due to all the aforementioned benefits, nowadays the car has become a necessity, and in the past decades the transport sector has experienced a significant growth in the world economy.

The number of cars on the planet has now crossed the billion mark and is increasing fast and 75 million units were forecasted to be added in year 2016 alone. The sales are expected to exceed 100 million units per annum by 2020 (Statista, 2016).

However, the pollution-related aspects of automobiles, in particular the diesel engine propelled vehicles, are now coming under focus. In this respect an extract from one UK newspaper (The Times) is quoted below:

- UK-wide there are 146 nitrogen dioxide monitoring stations
- A total of 26 of them breach EU/WHO guidelines
- From 2019 the Mayor of London, Sadiq Khan will create “ultra-low emissions zone” and diesel drivers will be charged £24/day to drive within city limits
- There is a growing call on government to introduce diesel scrappage scheme

Electric vehicles offer a zero (kerbside) emission and low greenhouse gas generation solution if the electricity is sourced from renewable energy means. Within the UK and other EU countries e-vehicles were introduced in a significant manner around 5 years ago and now represent 1% of auto population. In contrast we note that Norway’s proportion of electric and hybrid vehicles has reached 25%.

At Edinburgh Napier University a programme of research on electric vehicles was introduced fours ago with four charging stations installed at its three campuses. A further 12 charging stations will be added by the end of 2017. Table 4 presents the research findings of nearly four years of driving experience of a 100% electric vehicle, a Renault-Zoe (Figure 5 refers).

Figure 5. A 15kWp PV installation at Edinburgh Napier University which has been operational since 2005. The car in the foreground is University’s electric vehicle used daily since 2013 (left). A 35kWp PV roof was added at University’s Sighthill Campus in year 2015 (right).

Future low energy architectural design will need to address the incorporation of solar PV and electric vehicle parking bays on a micro- and community wind power projects on a macro scale.

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The Times, April 15, 2017, p. 29, London.

Investigating Optimal BIPV Energy Yield in consideration of Daylight and Thermal Performance in Residential Buildings

Bao Quan Ong, Dr Abel Tablada

Abstract: Singapore faces potential risk of an energy crisis due to her high dependence on imported fuels. Building Integrated Photovoltaics (BIPV) on building facades is an ideal alternate source of renewable energy, considering the strategic geographical location of Singapore with relatively constant high solar irradiance year round in all orientations. This paper focuses on the optimisation of BIPV shading devices on residential building facades (North and South) based on three performance indicators, (1) solar energy yield, (2) indoor daylight conditions and (3) solar heat gain. DIVA-for-Rhino plugin was used to perform the simulations on three experiments. Experiment 1 compared three shading device tilt angles, at 3m intervals. Experiment 2 compared two shading devices angles with a smaller interval of 1.5m. Experiment 3 proceeded to compare three shading devices lengths calculated based on 1/3, 2/3 and 3/3 arcs, by evenly dividing the lowest sun angles into three sectors. The study concludes that 30° tilt angle, double-spaced, 3/3 length BIPV is optimum for façades in Singapore's residential buildings taking into account net energy yield, daylight conditions and solar heat gains. On the other hand, 0° incline, single-spaced, 3/3 length BIPV is only optimum for the top floor.

Keywords: Solar architecture, BIPV, Shading devices, Building performance,

Introduction

Singapore has a consistently high consumption of energy per capita and this demand is expected to rise further in the future (APEC 2013). Currently, 95.5% of Singapore's energy production relies on import of non-renewable natural gases (EMA, 2015). Despite many options of commercially available renewable energy worldwide, solar energy has established to be the most feasible source of renewable energy in Singapore (NCCS, 2016) due to the relative high solar irradiance throughout the year. Taking into account large-scale solar farms are not feasible in land-scarce Singapore's context, Building Integrated Photovoltaics (BIPV) is one of the few alternatives to increase domestic energy generation.

Commercially available BIPV has various applications such as curtain walls and fenestrations. This study focuses on BIPV acting as shading devices due to the dual functions it provides favourable. Firstly, the addition of BIPV can assist in converting solar irradiance to electrical energy for consumption. Secondly, it can also serve as a shading device to reduce the direct solar irradiance that enters the interior (Mandalaki et al., 2014). Providing shading on building envelopes is an essential strategy for tropical passive design.

A number of papers have studied the use of shading device in tropical and sub-tropical regions. In the tropics, especially near the Equator, there is similar high solar exposure for both North and South facades as a result of the high altitude sun path year-round. The cooling effects of shading devices on facades have been reported by Secondini et al. (2011). Temperature reductions of 1.3°C (unventilated room) and 0.5°C (ventilated room) were achieved as compared to the absence of any shading device in a high-rise building in Penang, Malaysia. In addition, it was found that mixed shading was the most effective shading device followed by double horizontal shading (Secondini et al., 2011). Another study by Wong and Li (2007) investigated horizontal shading devices and their effects on cooling loads. It was found that a 600mm and 900mm shading device reduce cooling loads by 5.87% - 7.06% and by 8.27%- 10.13%, respectively (Wong and Li, 2007).

There are also multiple papers conducted on BIPV as facades and shading devices. Sun et al. (2011) studied an optimal angle of BIPV claddings in Hong Kong by comparing its energy outputs. Saber et al. (2014) studied PV performance and energy yield predictions on the Building Construction Authority (BCA) Academy in Singapore. Through data-collection and simulations, they have found that 30° slope is the most effective angle for PV panels on facades in Singapore. Mandalaki et al. (2014) investigated BIPV shading device optimisation in relation to visual comfort and solar energy yield. They have found that brise-soleil and single-inclined shading have effective solar energy gain while maintaining indoor visual comfort. However, their study was conducted in a Mediterranean climate. Tablada and Zhao (2016) estimated the potential energy yield by using PV panels on the roof and as shading devices in a number of residential building typologies in Singapore. They have found that all facade orientations were feasible for the installation of BIPV, however, if building height is higher than 42 m and 33 m for point and slab block respectively full energy self-sufficiency cannot be achieved. However, to the author’s knowledge, there is no investigation on the impact of the shading device’s dimension and position on energy yield versus indoor thermal and visual comfort in the tropics. This is crucial in Singapore’s context where high-rise public housing (also known as Housing Development Board (HDB)) takes up approximately 16.9% of land area to house 80% of the Singapore population. Hence, results in this study may serve as reference to determine energy yield by BIPV in HDBs and its possible applications across Singapore.

Therefore, this paper aims to study the effectiveness of BIPV installed on North and South facades of new Singapore residential flats. Using computational simulations, this paper aims to achieve the following:

1. To understand the impact of shading device angle, spacing and length on solar energy yield, daylight autonomy and thermal heat gain.
2. To propose preliminary recommendations on the implementation of BIPV as shading device on residential building facades in the tropics.

Methodology

The study consists of three simulation-based experiments to determine the optimum BIPV shading device. Experiments 1 and 2 compare three different angles of single and double shading respectively on North and South facades in terms of its solar energy yield, daylight levels and thermal heat gains in the interior. Experiment 3 uses the results from above experiments to compare three different lengths for BIPV shading devices.

Performance indices and modelling tools

Solar energy yield refers to the total annual electricity ($E_{electric}$) generated from a BIPV system. $E_{electric}$ is calculated from annual global irradiance which incidents on the BIPV shading device and takes into account efficiency (η) as well as the performance ratio (P) of PV panels (Quaschning, 2010).

The Daylight Autonomy (DA) is a climatic-based index which denotes the percentage in which a minimum -user defined- illuminance level is achieved by daylight alone for a specific time interval (Reinhart and Walkenhorst, 2001). In this study, DA is set at a minimum of 300 lux for general illumination of the living room from 0800 hours to 1800 hours. Light sensors are placed regularly at 0.85m height and 0.425m apart from each other. When natural daylight levels are insufficient during the analysed period, electrical lightings (LED light) are activated to bring illuminance levels to 300 lux.

In Singapore, Residential Envelope Transmittance Value (RETV) is used to calculate thermal heat gains by facades in residential buildings (BCA, 2008). The components of thermal heat gains on facades include (i) heat conduction through opaque walls; (ii) heat conduction through glass windows; (iii) solar radiation through glass windows. Shading Coefficients of fenestration is determined according to the facade orientation.

Sky Exposure Factor (Zhang et al. 2012) is defined as the percentage of visible sky from a given point to the overall sky dome. SEF can be calculated using Grasshopper ray-tracing calculation from a point (McNeel, 2011). It is useful for evaluating visual connection to the sky, which changes according to plot ratio and different factors of BIPV shading devices.

Rhinoceros (v5.12) and Grasshopper (v0.9) are the primary tools used for generating the models for simulations. DIVA-for-Rhino is a plug-in to Rhinoceros that harnesses Radiance backward ray tracers and Energy Plus to evaluate environmental performance of buildings and urban forms (Solemma LLC 2016). Using ASHRAE International Weather for Energy Calculations (IWEC) Data (Department of Energy, 2013), solar irradiance on BIPV surfaces and daylight autonomy of interior space are derived from the simulations.

Model description and simulation settings

The simulations were done in a generic context to maintain adaptability for future applications of the study. A model abstraction and layout from the most recent residential developments in Singapore was developed and placed in a five by four rectangular array to factor in realistic site conditions. The unit plan follows a typical 4-room unit in the HDB. The simulations focus on the living room (3.6m x 4.6m x 2.8m) as it has the highest daily occupancy (Figure 1a).

Three plot ratios (PR) 2.8, 3.4 and 4.0 are selected to represent current typical and possible future densities in Singapore's residential areas. Among the three plot ratios, 5 cases were selected for simulation. Each case was given a number, Case 1, 2, 3, 4 and 5 (Figure 1b). From PR 2.8, level 3, 9 and 15 were selected, while PR 3.4 and PR 4.0 only level 3 was selected as each case has a different percentage of visible sky and irradiance.

Building materials used in the simulation follow typical materials used in constructions. CIGS thin film PV is selected as shading devices due to its higher performance on warm and cloudy, conditions typical for Singapore's climate. (BCA n.d.)(Saber et al. 2014) which has a calculated area-weighted diffused reflectance of 4.73% and an area-weighted specular reflectance of 2.97% (Jakubiec and Reinhart 2014).

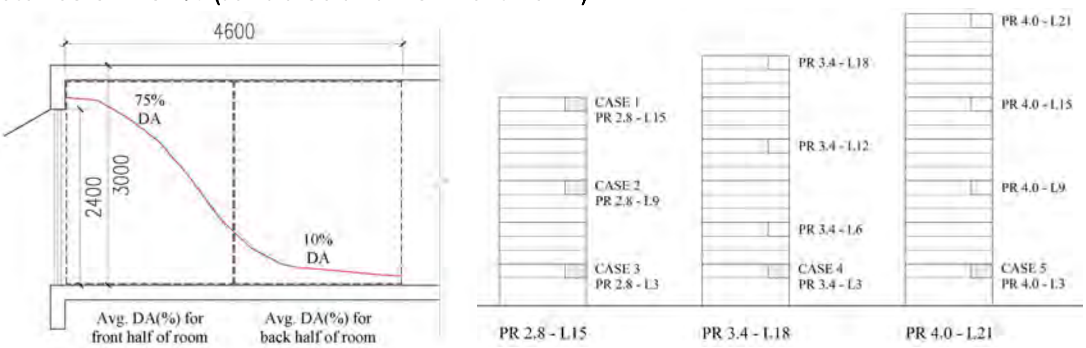

Figure 1: a) Cross section of living room and b) Section of housing blocks at Plot Ratio 2.8, 3.4 and 4.0 with position of cases 1 to 5

In this study, BIPV shading device was set to shade direct solar irradiance from 11:00h to 15:00h, which is the period with the highest solar irradiance and potential heat gain. Sun angles at 11:00h are lower than at 15:00h, therefore they are used for the dimensioning of the shading devices at different seasons. In order to determine the optimum shading device for North and South facades, several factors were considered (Figure 2). (i) Shading device angle (0°, 15° and 30°) (ii) Shading device spacing (1.5m intervals double shading and 3m intervals single shading) (iii) Shading device length (1/3, 2/3 and 3/3 arc lengths). The lengths are determined by equally dividing the lowest angles into three arcs. By taking the solstices as the limit, the different lengths shield different length of time in a year.

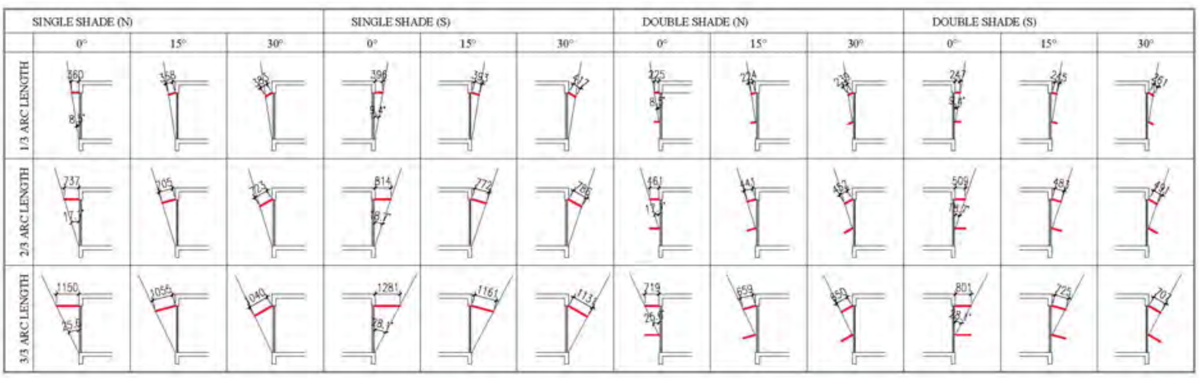

Figure 2: Matrix of possible shading devices

Results

Experiment 1

Experiment 1 aims to investigate the angle of BIPV shading device in relation to solar energy yield, daylight autonomy and thermal heat gains. The shading device spacing is 3m coinciding with floor to floor height. Sun angle is fixed at 17.1° for North facade and 18.7° for South facade (Figure 2: 2/3 Arc Length). Experiment 1 only simulates Cases 1, 3 and 5.

Solar energy yield increases as unit levels increase for both north and south facades and for all shading angles due to the higher SEF and solar exposure. North and South facades behaves similarly. However, North facades have lower energy yields due to the length of BIPV shading device for North facades being shorter than the South, as the sun angle in summer solstice is higher than winter solstice. Shadings with a slope at 30° achieve 10.2% and 9.3% higher yield than those with 0° for cases 3 and 5 respectively. Only for Case 1, 0° has higher solar yield than 30° due to its position at the top of the building with no surrounding obstructions as occurs for cases 3 and 5.

Regarding DA, 0° shadings have 26.7%, 29.6% and 28.6% higher DA than 30° shadings for cases 1, 3 and 5 respectively. This is expected as the SEF from indoors is higher when shading's slope is 0°. The differences between the shading slope angles are more accentuated for Case 1.

Energy used on electrical lighting to keep DA 100% (300 lux) is 1.8% higher on the South with respect to the North façade due to the slightly larger dimensions of the shading and the cloudier conditions of the sky from November till February. Taking into account both the BIPV energy yield and the energy used for electrical lighting, the net energy yield are calculated. The net solar energy yield from 0° is higher than 30°, for both North and South facades. In Cases 1, 3 and 5 the net solar energy after subtracting electrical lighting is lower for 30°. For Case 5, the net solar energy is negative, using more energy than the BIPV can provide. Thus, from experiment 1, 0° is a better option than 30° tilt angle.

Table 1 Net energy yield in Experiment 1 for North (N) and South (S) facades

Tilt angle	Case 1 (kWh)		Case 3 (kWh)		Case 5 (kWh)	
	N	S	N	S	N	S
0°	256.33	290.68	45.22	48.33	-1.13	2.98
15°	235.99	257.00	40.29	42.38	-2.91	-2.03
30°	207.94	226.55	36.66	37.24	-5.90	-5.48

Regarding the thermal heat gains by using RETV it is found that there is no difference between Cases 1, 3 and 5 since RETV does not consider site conditions. In terms of shading slope angle, 30° allows lower thermal transmittance (N: 29.8 W/m2, S: 30.6 W/m2) than 0° (N: 30.5 W/m2, S: 31.3 W/m2) for small margin.

Considering all results of experiment 1, it can be concluded that for single shading per floor, 0° shading device has overall better results than those with 30°. The net energy gain from 0° is higher than 30° while the higher RETV is not relevant.

Experiment 2

Experiment 2 aims to investigate the impact of reducing the shading device spacing from 3m to 1.5m. Only Cases 1, 3 and 5 are simulated in Experiment 2 and according to the results in experiment 1, only 0° and 30° will be simulated.

Solar energy yield is calculated through the summation of upper and lower panels. Similar to experiment 1, the higher the SEF and solar exposure the higher the solar energy yield for both north and south facades and for all shading angles. North facades have lower energy yields for the same reason as in Experiment 1. Shadings with a slope at 30° achieve 16.8% and 9.8% higher yield than those with 0° for cases 3 and 5. Only for Case 1, 0° has higher solar yield than 30°. Comparing experiment 1 and 2, double shading device gives 20.9% and 17.7% higher solar energy yield than single shading device for cases 3 and 5 respectively. However, energy yield from double shading in Case 1 on experiment 2 is lower than in experiment 1 due to the overshadowing effect on the lower slat.

Regarding DA, similarly to experiment 1, shadings with 0° tilt angle allows 7.5%, 15.5% and 10% higher DA than with 30° for cases 1, 3 and 5 respectively.

Energy used on electrical lighting to keep DA 100% (300 lux) is 2.9% higher on the South with respect to the North façade. However, comparing cases 1, 3 and 5 from both experiments, the benefit of using double shading device is substantial for 30° shadings and still evident for 0° shadings. Taking into account both the BIPV energy yield and the energy used for electrical lighting, the net energy yield is calculated. Comparing between experiment 1 and 2, less electrical energy is required in experiment 2 due to the improved DA. The net solar energy yield from 30° is higher than 0°, for both North and South facades.

Table 1 Net energy yield in Experiment 2 for North (N) and South (S) facades

Tilt angle	Case 1 (kWh)		Case 3 (kWh)		Case 5 (kWh)	
	N	S	N	S	N	S
0°	230.66	263.98	63.84	78.17	14.64	28.63
30°	249.62	267.13	81.53	85.79	25.40	30.10

Regarding thermal impact of shading tilt angle, RETV is lower for 30° in North and South at 28.8W/m^2 and 29.6W/m^2 respectively. While thermal heat gain is higher for 0° in North and South 29.5W/m^2 and 30.1W/m^2.

Overall, the results from Experiment 2 showed that 30° shading device performs better than 0° shading device as net energy gain from 30° is higher than 0°. Even though DA conditions for 0° is better than 30°, the difference in DA is less than the difference in solar energy yield. In addition, thermal heat gains for 30° is lower than 0°, showing there will be better thermal comfort.

Experiment 3

Experiment 3 aims to investigate the length of BIPV shading device in relation to solar energy yield, daylight autonomy and thermal heat gain. The results from experiment 1 and 2 determine that optimum shading device spacing is at intervals of 1.5m and BIPV optimum angle is fixed at 30°. The length (1/3, 2/3 and 3/3 arcs) was determined according to sun angle as explained in the Methodology section. All Cases 1, 2, 3, 4 and 5 were simulated in Experiment 3.

Shadings with 3/3 length achieve higher energy yield than those with 1/3 and 2/3 lengths as larger surface area receives higher total irradiation.

Regarding DA, 1/3 length shadings have higher DA than 2/3 length and 3/3 length shadings for all cases. This is expected as the SEF from indoors is highest when shading has the shortest length.

Energy used on electrical lighting to keep DA 100% (300 lux) is compared between different lengths. Table 2 shows that net solar energy yield from 3/3 is higher than 1/3 and 2/3, for both North and South facades. The reduction in DA in 3/3 is the least significant in reference to solar energy yield.

Table 2 Net energy yield in Experiment 3

Length (arc)	Case 1 (kWh)		Case 2 (kWh)		Case 3 (kWh)		Case 4 (kWh)		Case 5 (kWh)	
	N	S	N	S	N	S	N	S	N	S
1/3	133.6	137.4	67.7	65.7	36.8	35.5	18.8	14.7	1.7	-0.4
2/3	244.2	256.6	124.1	127.3	78.0	79.1	53.5	53.9	31.1	29.8
3/3	328.6	293.3	152.4	159.8	97.2	103.4	67.6	71.3	40.2	42.9

Regarding the thermal performance, lower RETV are obtained for shading with 3/3 length in comparison with 1/3 and 2/3 lengths (Table 3). Therefore, double 30° slope shading with 3/3 length is the optimal shading device for both North and south facades on all cases except for Case 1 in which single 0° slope shading with 3/3 length is the optimal option.

Table 3: RETV of BIPV shading device at various lengths

	RETV (N) (W/m^2)	RETV (S) (W/m^2)
1/3	30.99	31.81
2/3	28.83	29.57
3/3	27.49	27.59

Overall building production

Using the optimised configuration, an estimate of net solar energy yield per floor and facade orientation can be calculated according to the obtained exponential equations shown in figure 3. The entire net solar energy yield considering North and South facades were also calculated. The study shows that BIPV shading devices for North and South facades can produce 92 639.1kWh of the 281 534.4kWh consumed annually which equates to 32.9% of annual consumption of a single block (EMA, 2016).

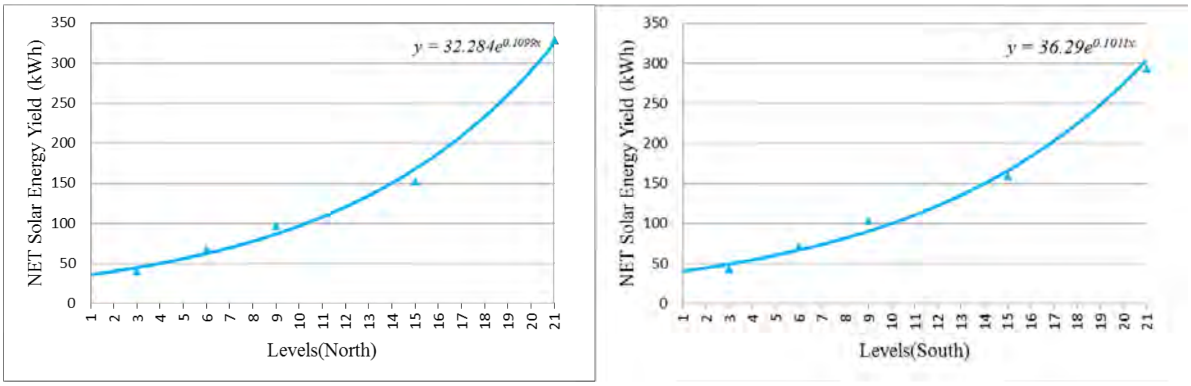

Figure 3: Net energy yield according to the position of BIPV shading devices (building level)

Conclusion

A series of experiments were conducted in this study to understand the impact of shading device angle, spacing and length on solar energy yield, daylight autonomy and thermal heat gain. These results were subsequently used to compare results of various shading device properties in order to optimise BIPV shading device. Experiment 1 compared different single BIPV angles while Experiment 2 compared between single and double BIPVs. Lastly, Experiment 3 compared the optimisation of various lengths of BIPV shading device.

In conclusion, the following guidelines can be determined from this study:

1. The optimum shading device is a double BIPV with 3/3 arc length (650-700mm) and 30° tilt angle. This may be applicable on new buildings or in retrofitting projects.
2. In the case where only a single shading device can be installed, 3/3 arc length, 0° shading device is preferred.

The total net solar yield amounts to 92 639.1kWh for North and South façade for a single block, which is 32.9% of electrical consumption of the block. When coupled with additional solutions such as roof PV arrays, it can provide an even larger contribution as a renewable energy source. Hence, findings in this study show significant energy yield through BIPV shading device and suggest feasible applications in Singapore HDBs.

Further studies will include the optimisation of BIPV dimensions and positions on East and West facades as well as other intermediate orientations. The effect of adding BIPV on facades with balconies and exterior common corridors will also be explored.

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Solar energy in the urban vertical fabric

Harald N. Røstvik

Professor,
University of Stavanger, Norway. harald.n.rostvik@uis.no

Abstract: By using a recently completed Nearly Zero Energy Building (NZEB) house in Norway as a case, this paper discusses the chosen strategies and explores their wider potential. The case is an innovative compact house addressing the housing shortage through minimising area-, volume and building costs, while exploring the solar energy potential using BIPV on vertical walls in a Northern climate. Advantages and disadvantages are evaluated.

Keywords: NZEB, cost, housing, solar

Introduction

The case building is constructed 30 years after one of Europe's first modern NZEB designs was built in the same region. It is interesting to compare the technical solutions and the costs available at that time and now. Such history lessons are also useful for teaching university students of architecture and urbanism about advances in passive and low energy design, as well as the remarkable technological developments. The house 30 years ago was not as energy efficient as the new one is. It had a total energy need per m^2 more than double of the new house. In order to deliver so much energy it had to use a combination of solar PV, solar thermal, wind power and log fire (kakkelovn). It had batteries to store electricity and two thermal mass stores to store heat, one rock bed and one water tank. The many technical devices necessary led to co-ordination challenges between them. Grid connection was not possible at the time. It is interesting to observe that after all these years and with grid connection later having been widely used in NZEBs to balance the scattered delivery of energy from solar and wind, the tremendous advances and cost reductions in battery technology now again opens up for the possible future use of batteries to make buildings and neighbourhoods energy autonomous. But such a technological approach can only be successful if energy need is lowered through the traditional methods of passive and low energy design. In the following chapters a listing of the described methods are put figures to, after which the potential of delivering the energy need from solar is discussed.

The main advantage of such an all electric solution is that it is technically much more clean cut and avoids all the co-ordination challenges in solutions using several combined energy sources, as designed into the first NZEB.

Planning

All construction is energy demanding and produces greenhouse gases from the very start, excavation of the site, through material development, transportation, manpower and demolishing. The role of the architect is hence also to avoid planning larger areas and volumes than necessary. The goal of which is to reduce the resources going into the production of buildings, cities and infrastructure. A building that is compact and rational will always have a better chance of becoming energy efficient and a user of renewable energy. It is also cheaper. Total building costs for housing in Norway are on average NOK 70 000 per m^2 (GBP 64 000) including finance cost, project development and profits. This includes site costs of NOK 6 000 (GBP 5 500) per m^2 (Norsk Prisbok, 2014). To understand the cost structure is particularly important for architects and planners so that housing costs can be lowered to accommodate the needs of the young and the first time buyers.

In the particular case in Norway, analysing and questioning the area need with the client led to 45% floor area reduction, from 105 to 58 m^2. The process was very natural and the client afterwards expressed to nationwide media that he is very pleased with the result (Teknisk Ukeblad, 2017). He even expressed that the storage space and main rooms felt more generous than anticipated during the planning process. See Figure 1.

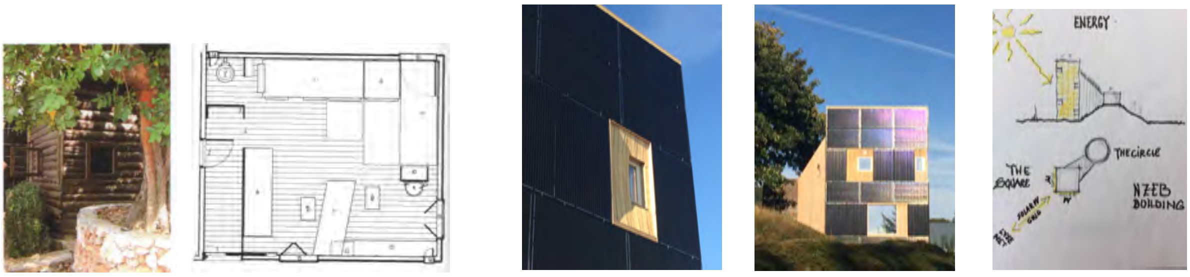

Figure 1. Left two: Plan, picture Le Cabanon. Ill: Byggekunst. Right three: Case house. Ill: The Architects.

The planning process started with discussions between the client and the architect where the first bubble diagram sketched by the client was analysed. The first example used was the fair life one can have in a caravan in a mobile situation. The client then rented one and went on summer holiday on the $8m^2$ with his young son. It worked perfectly well for them and based on this, new planning discussions took place, bringing the total area down to the as-built size. The second example used was Le Corbusier’s Le Cabanon at Cap Martin, in southern France (Byggekunst, 2007). Le Cabanon was only 16 m^2 and the famous architect and his wife lived there during the summers on $8m^2$ per person (Figure 1). The compact thinking had been inspired by Le Corbusier’s long haul flights to other continent. He had seen how compact the cockpit and the toilets were on board. Le Cabanon contained a combined living and sleeping room, toilet and a small breakfast kitchenette, as there was a restaurant next door, where they ate lunch and dinner. Showers were taken outdoors or by swimming. Le Cabanon was of course for the summer season only. The third example was that of world famous philosopher Ludwig Wittgenstein who wrote great works in a 59 m^2 log house on a mountain shelf in Skjolden by the Sognefjord in Norway (Stiftinga W, 2017).

In Norway, where the climate is harsh, the demand for insulated construction and more indoor space is of course pressing, to avoid people sitting on top of each other in the long dark Nordic winters. But still, there is a lesson to be learnt from Le Cabanon about compact, rational space planning. For every square meter one can save, land and monetary resources are saved, so is energy, both for construction and the running of the building throughout its life span. The case house is composed of a living square of 4,2mx4,2m internally and a wet room circle with a diameter of 3,0m. The compactness of the $58m^2$, two and a half person Norwegian case house, is in strong contrast to the constantly growing average *living area per person* in Norway, which has doubled since 1960 when it was $29m^2$ per person. In 2000 it was 51 m^2. It is now $56m^2$ (Statistisk Sentralbyrå). Simultaneously the *average household size* has become smaller in the period. In 1960 there were 3,3 persons per household, by 2000 there were 2,3. This is the same as in 2015. The *area size* of housing (the average figures for detached-, row- and flat housing) has increased dramatically in the period, in spite of the fact that households have been reduced. In 1967 there were $89m^2$ per household. Thirty years later in 1997, 114 m^2, an increase of 28% during a period where the household size has been reduced by 30%. The Norwegian case house of $58m^2$ for two grown-ups and a now 6 years old child, say 2,5 persons, is $23m^2$ per person. The question arising is hence if such a compact building strategy lowers the quality of living? The issues addressed in the following relates to this as it discusses the pros and cons of the compact solutions and the architectural and technical challenges it poses.

Daylight

A slim plan (compact) versus a fat plan (spread out) has advantages and disadvantages. A fat plan means that everything can be located on one floor, while a slim plan means the house or apartment may have to go vertical over several floors, to achieve the same total floor area. The consequences of this are many. A slim plan offers the possibility of placing several windows in a room and to orientate them in different directions on several walls, which increases the use of daylight and direct sunshine. A fat plan will be deeper and it is more difficult to daylight the parts of the rooms that are located far from window-walls. But the slimness' verticality poses universal design challenges with the stairs connecting floors.

Universal design

A house or flat on one floor only is normally seen as the best in a total life span cycle. If people want to live in the same place in spite of health related limitations of their ability to use stairs, this is an argument for the one floor fat plan. If, however, the need for more compact living is driven forward as an argument to densify cities, both arguments have to be balanced and counterweighted against each other. If the option of going slim and vertical is chosen, it will be the job of the planner to ensure that it is possible to function on one floor most of the time by having the living room, sleeping-, kitchen- and bathroom facilities on at least one floor. This can sometimes be challenging if not planned for in advance, but it is possible if planned from the outset. In the case of the Norwegian building, the first floor is planned with this in mind without alterations, provided a sleeping facility is accepted and the day-sofa in the living room is used as bed at night. At the ground floor, such autonomy can also be achieved by installing a very light kitchen facility. Everything else is already in place.

This leads to the issue of access. External access to the middle floor in the case house is ensured by the used on a long sloping ramp looking like a barn access bridge. This is also the main access to the house, as the section in Figure 1 shows. Internal access for everybody between floors, also the handicapped, is possible by installing a simple weight-based stair lift. The step between the floors is all straight runs without any bends that normally complicate matters anyway and increases future lift costs. The straight run allows the use of a fairly simple and inexpensive lift, if a lift later becomes necessary.

Insulation

In the Nordic climate a lot of insulation is necessary to make buildings energy efficient in winter. With the new EU Directive, Nearly Zero Energy Buildings (NZEB) introduced from 2020, the housing market is driven further towards demanding energy efficient buildings that use new renewable energy. In Norway total wall and roof thicknesses already reach 300 – 500 mm. This is highly material-, labour- and finance-demanding. It also demands a bigger part of the site, as walls get thicker (Figure 2). This challenge has been addressed in the case house where it has been a goal to reduce insulation thicknesses wherever possible in order to reduce the footprint on the site. This is particularly important in dense situation in cities where densification is a part of the overall environmental strategy. Therefore new insulation types have been tried out. The compact-insulation applied has led to a reduction of wall thickness from 500 to 150 mm. Described from the outside it consists of 100mm Kingspan foam, 30mm Rockwool and a reflective layer of plastic. An LCA analysis will be carried out.

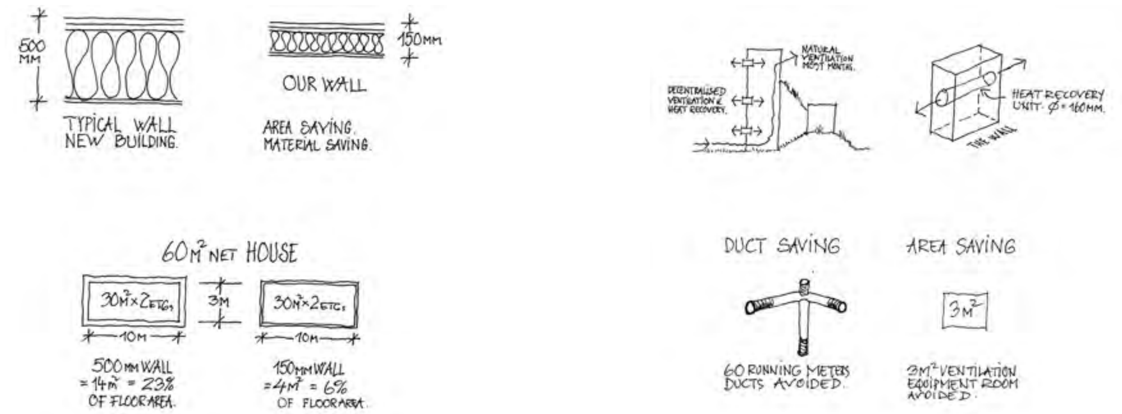

Figure 2. Left: Area, cost and material saving slim walls. Right: Decentralised heat recovery gains.

Ventilation

In order to achieve the NZEB standard, forced balanced ventilation and heat recovery is necessary. Most projects in Norway end up with that strategy. The case project has tried to question the need for such a heavy technology-dependent approach by leaning more towards a passive and low energy strategy. However, in the Norwegian winter months natural ventilation will not work without heat recovery, if a NZEB level is sought.

In the case project, natural ventilation is part of the strategy most of the year, normally 9 months. In the coldest three months of the year, forced ventilation with heat recovery is necessary. The applied heat recovery system consists of decentralised units mounted through the walls in a 160 mm diameter duct. Through this short duct, of wall thickness only, a fan in the duct extracts used indoor air. On its way out, the warm air passes through a ceramic cylinder that stores the heat. After ten seconds the fan switches air direction and sucks fresh outdoor air in through the same duct, thus heating the air when it passes through the warmed ceramic cylinder. There is one such small duct in each room, only a couple of rooms have two. They were very easy to install and are inexpensive compared to a centralised duct and air handling unit solution. A switch next to the light switch in each room can also switch them off manually any time and one by one. A centralised HVAC system is hence avoided. The saving is considerable: A traditional technical room for the air handling unit and the central heat recovery is eliminated. This is in itself a reduction of $3m^2$ ($8m^3$) per housing unit. In addition 60 running meters of ventilation ducts, that a standard centralised HVAC system would need, are avoided (Figure 2).

Through the combination of the strategies mentioned above, the energy need of the house is considerably reduced - to only 5 200 kWh per year. The following chapter will put this energy need into perspective and look at how renewable energy can deliver all of it.

Energy

The average energy need of a Norwegian single-family housing unit is 25 000 kWh per year and for a flat 12 000 kWh. Single family housing energy use is 80% electric energy and 20% wood or pellets (SSB, 2014). 99% of all electricity in Norway is hydropower-based, so it is considered clean. The energy need for the case building has been lowered to Passive house standard based on the mentioned energy efficiency measures. This led to a calculated annual energy need of 5 200 kWh, which is divided between the uses shown in Table 1.

Table 1. Energy need of case building. Source: E-tech

Domestic hot water	2 050 kWh/year
Space heating	1 050
Technical equipment	1 100
Lighting	700
Fans	300
Sum	5 200 kWh/year

Solar energy

The total energy need is delivered by a grid-connected Building Integrated Solar Photovoltaic (BIPV) electric system constituting the cladding of the vertical southwest and southeast walls. The PV modules replace other facade materials, so extra costs are minimal.

Angle of inclination

In countries close to the equator, the sun is high in the sky most of the day and year. In all the Scandinavian countries, however, the sun is low in the sky in that part of the year when energy requirements are greatest – in winter. Many international tables of radiation are therefore somewhat misleading, because they are calculating solar radiation onto a horizontal plane. Such tables do not allow for the fact that a considerable amount of solar radiation falls on vertical planes, e.g. walls of buildings, during winter the months (Røstvik 1992, 36-37). Table 2 shows the relationship between the angle of the solar collector to the horizontal for domestic hot water as well as for both space heating and domestic hot water. Although this is based on thermal energy delivery, the relationship to electric energy is comparable. It shows that in a Scandinavian situation a vertical wall integrated solar installation delivering space heating and domestic hot water will catch 97% (0,97) of the maximum, or considered the best 100% (1,00) that a 45 degree inclination delivers. This clearly shows that a vertical wall is an almost ideal location for solar modules, not least because it can also replace other, sometimes expensive, cladding materials.

Table 2. Inclination of the solar collector – relative change of degree of effect in Norway.

Angle to horizontal	0°	15°	30°	45°	60°	75°	90°
Domestic hot water	0,71	0,85	0,94	1.00	1,00	0,98	0,88
Space-heating and domestic h.w.	0,59	0,74	0,89	1,00	1,06	1,06	0,97

Source: Røstvik (1992).

Table 3. Orientation of the solar collector, relative change of degree of effect in Norway.

Degrees from the south	0°	15°	30°	45°	60°	75°	90°
Domestic hot water	1,00	0,99	0,97	0,93	0,88	0,81	0,73
Space-heating and domestic h.w.	1,00	0,98	0,95	0,89	0,81	0,73	0,64

Source: Røstvik (1992).

Orientation

The directional orientation of the solar collector has less significance than most people realize. The best results north of equator are achieved if the collector faces due south, but slight deviations from this have little significance for the yield (Røstvik 1992, 37). Table 3 shows this. In the case of space-heating and domestic hot water where due south delivers maximum 100% (1,00), an orientation 45 degrees west of east or south will deliver as much as 89% (0,89). A west or east orientation, 90 degrees from south, will deliver 64% (0,64).

Lessons learnt in 30 years

The remarkable cost fall that have taken place during the last decade continues and solar PV systems will in due time become as cheap as most cladding materials. Solar PV modules are already cheaper than the more expensive marble and metal cladding facades. Reflection from neighbouring buildings and from snow will increase production. So will a well-ventilated façade. A gap between the rear side of the absorber and the constructed wall behind, secures an up draught that cools the solar cells and increased their electricity production. Construction detailing hence also becomes important.

The new Norwegian case house with its modest energy need is all electric and grid connected, it sells surplus electricity to the grid and buys back when it cannot deliver its own energy. The problem with this in Norway is that the selling of the house's surplus electricity generates very little income, only 20% of the normal cost of electricity per kWh when buying from the grid. So selling to the grid is not stimulated and does not pay off. This is contrary to many other countries that have introduced incentives by copying the initial German feed-in-tariff that encourages the selling of renewable energy to the electric utility's grid by offering payment way above the normal price per kWh. The consequence is that in Norway the lack of incentives stimulates the use of off-grid systems, totally energy autonomous solutions, where a kWh electricity produced by the house has the same value as the bought one by reducing or eliminating the need for buying electricity from the utility.

It is hence ironic that the electric utility companies that do not support and subsidise solar power delivered to their grid may undermine their own future by not paying properly for delivered solar electricity. With the fast development in battery technology, with falling prices and more compact solutions, battery storage may become a viable alternative both technically and financially, especially in neighbourhood solutions or village level local grids. The growing interest for smart buildings, smart neighbourhoods and smart cities underlines this and so does the growing interest in electric vehicles and bikes. 48% of all sold new personal vehicles in Norway during January 2017 were Battery Electric and Plug in Hybrids. They will be connected to people's homes and the vehicle batteries will share energy with the house and vice versa. This opens up a new world of opportunities that leads to community energy autonomy, while simultaneously evening out the peak load burdening the electric grid.

Discussion

Vertical solar facades may suffer from trees or neighbouring buildings casting shadows on the façade, but in locations where that is not the case, vertical facades may work very well. They deliver energy during the part of the year when the energy need for heating up north is highest. A solar PV façade, not a thermal one as discussed above, will achieve similar results. It may even deliver electricity during night in the most northern regions of Europe because in the summer the nights are very long. In some places the sun hardly sets in the summer. In latitudes around 65 degrees north the sun is up 21-24 hours a day during June and July. This is of course extreme, but it means that a solar absorber will deliver energy almost all through the night and can be orientated towards northeast or northwest, if energy is needed in the summer time.

The point here is that the efficiency of a solar absorber depends on many local factors. Vertical facades are useful producers and orientation does not have to be due south. Although the production is not maximum with such tilts and orientations, adding modules to increase the capacity of the system, with only marginal costs, can easily compensate the loss.

Conclusions

Verticalization and compactness are interesting measures to densify cities and as illustrated by the case building, compactness does not have negative effects only. There are many positive effects of densification, provided the distance between buildings is adequate. As the cost of solar is reduced and modules become competitive with traditional façade cladding materials and not only the more expensive ones, as the case is today, solar facades can become widespread. This will lead to less worry about performance. Until now, the solar advocates have been very particular at underlining that it is necessary to have unobstructed lines to catch sunshine. They argue for a stronger law that protects people right to sunshine. That is good from a health point of view and also to increase the use of daylight in buildings. Although this is true now, it is important to underline that this view is based on a situation where solar is so expensive that getting the most out of every module is a must in order to defend the solar equipment investment. This would call for stringent regulations and laws protecting a building owner against shade cast from neighbouring buildings. This may be a “truth” of the past, because sunshine is not only useful as direct sunshine, but also reflected. With verticalization and densification of cities it becomes impossible to control sunlight lines to prevent shading of solar modules. If we accept that shading will occur in dense cities, we should look at reflection from neighbouring buildings as an opportunity also. Sunrays are almost completely reflected from glossy white facades (think of glare in white vernacular urban settings) and reflective mirror glass in buildings. In the PLEA15 paper “Consequences of Verticalization” Paula Bregiatto et al showed how verticalization resulted in poor environmental conditions and accumulation of pollutants (Oliveira, P.B. et al, 2015). The paper described how the 2002 Master plan of Sao Paulo was updated in 2014 to reduce the massive exploitation of land. This is an example of planners using the master plan to adjust to changing conditions and experiences as time goes by. Such adjustments should also take place as regards the role of solar reflection when verticalizing cities. It is up to the planners to stay updated so that new technologies like solar is given the *best conditions possible,* as it can never be perfect.

In another PLEA paper "Comparing the solar performance of urban forms in London", Chatzipoulka, C. et al studied how urban geometry had an impact on solar availability in twenty-four urban forms in London (Chatzipoulka, C. et al, 2015). They found that solar availability on building facades in the urban setting naturally varied with deviation of building height and the sun's altitude: the lower the altitude, the greater the influence. Based on this general guidelines can be developed.

It does, however, appear that most studies are based on monitoring program software that does *not* handle uncontrollable reflection from neighbouring buildings. Instead they just study direct sunshine, which is only a part of the solar contribution. More precise models that include the consideration of reflection would be helpful and based on such modelling; more realistic guidelines can be developed.

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Towards an Eco-City Future: A Renewable Energy Supply and Smart Mobility Symbiosis

Olivia Zara[1,2], Eugenio Morello[1] and Vanessa Gomes[2]

[1] Laboratorio di Simulazione Urbana Fausto Curti, Dipartimento di Architettura e Studi Urbani, Politecnico di Milano, Milan, Italy;
[2] School of Civil Engineering, Architecture and Urban Planning, University of Campinas, Campinas, Brazil;

Abstract: Taking into account that Brazil possesses 84% of its population living in cities and that transportation constitutes a significant portion of the urban cost matrix, balancing city growth, energy consumption and transportation (including maintenance and operation of the road system) represents a great challenge to be overcome. Though 65.2% of the Brazilian electricity mix is based on hydropower, the country has faced strong unfavorable hydrological conditions. This research hence had the overall objective of investigating solar energy potential to supply renewable energy for residential and public transportation end-uses. The method comprised a general analysis of the city of Londrina, in Brazil, and an indirect quantitative relational methodology of data constitution for computing energy consumption and generation potential. We followed the 'ecosystem approach' on sustainable urban development to establish present and future residential energy consumption scenarios for the studied city. Our calculations showed that, when the whole urban perimeter is occupied, installing PV arrays on 10% of the residential roof surface would produce a 75% energy surplus that, if added to PV generated by adoption of a massive local renewable energy production (MassREP) system, Londrina would be able to also supply a new, renewable electricity-powered smart mobility transportation system.

Keywords: Urban Metabolism, Energy Urban Planning, Solar Energy, Distributed generation, Smart Mobility.

Introduction

As of 2008, over 50% of the world's population lived in urbanized areas (UN, 2014). Due to a car-dependent development culture, urban sprawl and high agglomeration of built environment, people and economic activities in one place, urban settlements represent bulk resource (energy, water, land and materials) consumers, generating immense amounts of waste, high thermal capacity material surfaces and heavy emission of pollutants to the immediate and global environments (Bai, 2007; Niemelä et al., 2011; Pincetl et al., 2012). Such negative tracks are expected to worsen as urban areas play their protagonist role in population growth forecasts and the dark path we witness today concerning the problems of pollution, resource scarcity, climate change and extreme poverty become more critical. Hence, sustainable urban planning approaches that regulate a balanced view of future developments must be increasingly consolidated.

The relationships among city growth, energy consumption and transportation represents a great challenge to be overcome in Brazil. Over 84% of the population lives in cities (IBGE, 2010), meaning that at least 168 million people use some kind of urban transportation, private or public, individual or collective. Transportation also represents a significant portion of the urban cost matrix. Though 65.2% of the Brazilian electricity mix is based on hydropower (BEN, 2015), the country has faced strong unfavorable hydrological conditions, which restates the importance of investigating other potential renewable energy sources to sustain transitioning towards a less dependent or fossil-free society. This research hence had the overall objective of investigating solar energy potential to supply renewable energy for residential and public transportation end-uses for the city of Londrina. Such symbiosis constitutes an innovative urban energy ecosystem and an important enabler for Brazilian eco-cities in the near future.

The method comprised a general analysis of the selected city and an indirect quantitative relational methodology of data constitution for computing energy consumption and generation potential. We followed the 'ecosystem approach' on sustainable urban development to establish present and future residential energy consumption scenarios for the studied city. A top-down methodology was applied to estimate current energy consumption for each residential typology defined. Next, a bottom-up approach was applied to derive consumption for future typologies defined by the existing city zoning plan. Finally, we assessed the potential to not only counterbalance such consumption, but also to feed a new smart mobility transportation system, through adoption of a massive local renewable energy production (MassREP) system.

The Ecosystem Approach

Amid all movements and strategic views towards sustainable urban development, the 'ecosystem approach' stands out for its comprehensiveness and systemic thinking. This theoretical approach helps to frame the chaotic web of existing variables and relationships by essentially enabling partial analysis of a system without losing sight of the broader context in which it appears and by which it is influenced (van Bueren et al., 2012).

Within the ecosystem approach's scope, different 'sub-approaches' frame the built environment as an ecosystem that needs to balance its inputs, outputs, use and extraction of resources and, by doing so, enable provision of methods and tools for environmental assessment. The 'flows sub-approach', in particular, defends that city survival requires constant resource inputs and outputs flowing through it, at immense transportation and energy expense to sustain such 'metabolic' work. By seeing cities as quantifiable entities, in which the inputs and outputs of materials, resources, energy and information are measurable (van Bueren et al., 2012), concepts such as 'Urban Metabolism', 'Circular Metabolism' and 'Carrying Capacity' emerged and gained traction in the past years.

Urban Metabolism is the collection of technical and socioeconomic processes that occur in cities, and result in growth, production of energy, and waste elimination (Kennedy et al., 2007). Considered as fundamental to sustainable city development (Kennedy et al., 2012), such metabolic work enables system and technology management for reintegrating natural processes, increasing energy and resource use efficiency, and recycling waste (Newman, 1999). Shahrokni et al. (2015) further elaborated the concept of 'smart urban metabolism' (SUM), which aims at combining real-time user-generated data to offer knowledge on energy and material flows as close as possible to reality, and the use of calculation engines that can provide feedback related to sustainability indicators set by a city.

Smart Mobility

Mobility efficiency within a city, region or country is closely related to the economic and social development. Transportation facilitates access to work, services, education and leisure. In large cities, it constitutes a significant portion of the urban cost matrix. In some cities, the amount spent on transportation - including maintenance and operation of the road system - is larger than the share committed with basic public services such as water, electricity and sewage supply.

The term ‘smart mobility’ is embedded within the ‘smart city’ framework, which promotes the use of information and communication technologies (ICTs) to create *“a particular form of spatial intelligence and innovation, based on sensors, embedded devices, large data sets, and real-time information and response”* (Komninos et al., 2013), that helps more efficient functioning and maintenance of urban physical infrastructure, as well as managing natural resources wisely through participatory governance, all of which supporting a strong and healthy economic and social development (Caragliu et al., 2011). In that line, ‘smart mobility’ refers to logistics and new transportation systems which improve urban traffic and inhabitants’ local and international accessibility through ICTs (Giffinger, 2007). Smart mobility is usually associated with ‘green mobility’ standards, which aims at expanding public access and decreasing environmental, social and economic impact through the creation of a sustainable transport system that reduces air and acoustic pollution, greenhouse gas emissions, road congestion, accidents, and that also optimize territory consumption.

The Energy Issue

Transportation is vital to the survival, well-functioning, development and, particularly, to the quality of life in cities. In Brazil, the transportation sector is the second largest energy consumer in the country (32,5%), right after industrial consumption (32.9%) (BEN, 2015). Sadly, 82% of this consumption comes from non-renewable sources.

In 2014, the total anthropogenic emissions associated with the Brazilian energy matrix reached 485.2 Mt CO_{2eq}, from which 46% (221.9 Mt CO_{2eq}) were transportation-driven. The current scenario could be reversed if individual mobility is decreased; alternative renewable energy sources are taken into the sector; and massive investments in comfort, safety and quality are made in public mass transportation, since it consumes 5-10 times less energy per passenger.

The Brazilian electricity matrix represents 17.2% of the total end use and is mainly consumed by the industrial (38.7%) and residential sector (24.8%). 65.2% of it comes from hydro power plants. More recently, other clean energy sources have received encouragement, such as biomass (7.4%) and wind power (2%) (BEN, 2015). However, taking into account that only 0.04% of this electricity reaches the transportation sector; the huge solar radiation available in the country; and also the recent drought periods, solar thermal energy represents an interesting alternative to be explored, especially if we consider that dry periods are associated with increased solar potential due to low interference from clouds and more intense solar radiation. Furthermore, solar energy is considered as a renewable and inexhaustible energy source. While the PV panel production indeed has its own impacts, the electricity generation process does not emit SO_2, NOx and CO_2: all of them greenhouse gases contributors to global warming and with harmful effects on human health.

Our case study: Londrina

As a young city that has undergone rapid growth during its 82 years, Londrina is the fourth most economically influential city of Southern Brazil. Located 390 km from Curitiba, the state's capital, Londrina is one of the most dynamic cultural centers of the country and presents an important potential for future urban growth and development. The city has a population around 554.000 inhabitants, but also conforms a metropolitan area with over one million citizens and conurbative spatial integration with two neighboring towns. At an altitude of 608 m, the urban perimeter is set on a fertile land, containing five hydrographic basins with permanently protected areas of original bottom valley vegetation.

Londrina's urban form is characterized by two sites of high verticality, density, income and infrastructure (i.e. the city center and '*gleba palhano'* neighborhood); a region of medium density, income and infrastructure in the center outskirts; a region of low density, high income and medium infrastructure in the southwest, dominated by gated communities; and vast areas of peripheral neighborhoods in the north, east and southeast with medium to high density and medium to low income and infrastructure, housing several social projects and a few irregular occupations (Figure 1a). This reveals an evident urban socio-spatial segregation, result of innumerous unplanned developments and growth.

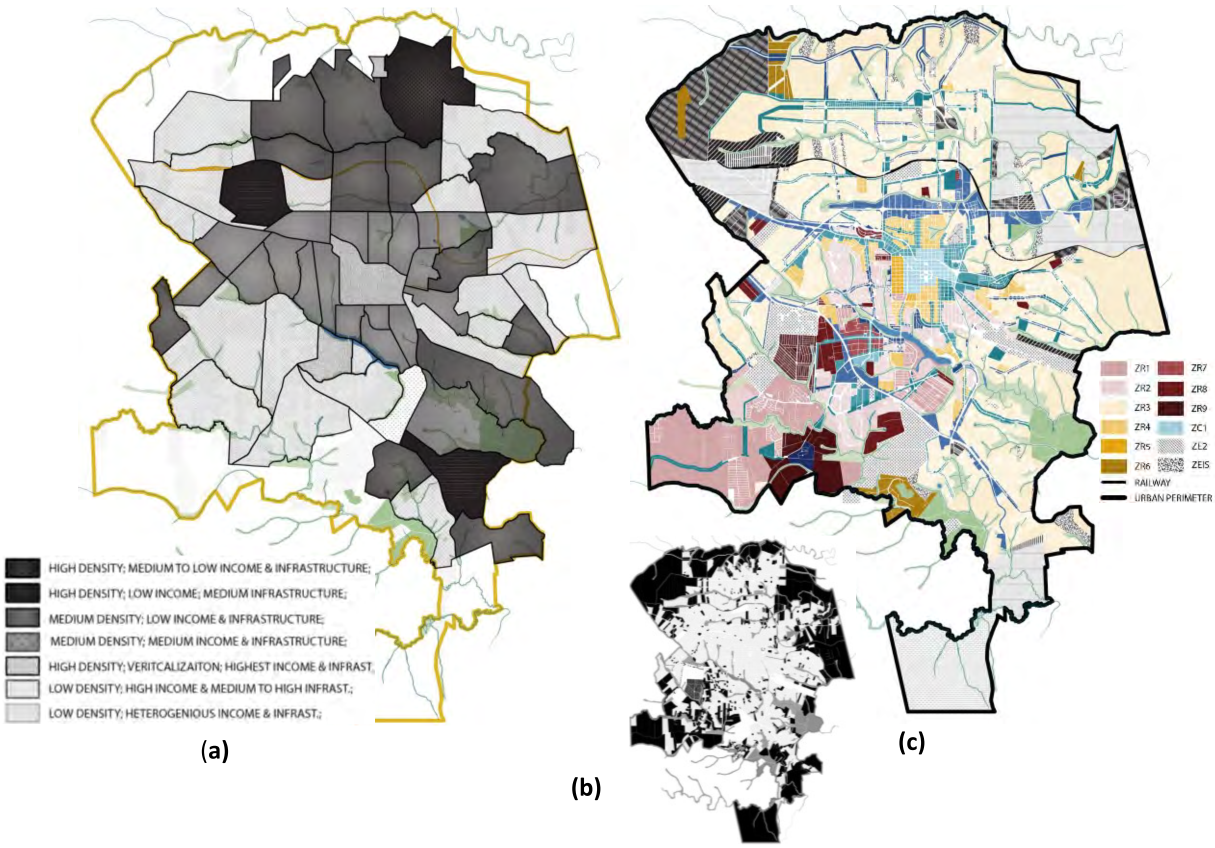

Figure 1: (a) Social, Economic and Infrastructural Synthesis Map adapted from Londrina Environmental Atlas (Barros et al., 2008); (b) Urban voids; (c) City zoning plan

Most of the services and shops are located in the central area and most industries are located in the few main roads that cross the city, consequently, so are the employment offers, the desired routs, the public transportation's passenger demand and the traffic jams in peak hours. This fact causes a considerable daily displacement due to the distance between jobs and residences. Additionally, the city has a comparatively low mobility rate and a high number of individual vehicles per person (0.65, according with CMTU, 2013). Furthermore, the few existing terminals are concentrated in the central, northern and southern regions, leaving the west and east uncovered, which result in loaded, less comfortable lines and larger displacements.

Londrina's energy consumption profile is basically composed by an *annual electricity consumption* of 1,356,129 MWh (in 2013), being roughly one third of it (429,974 MWh) demanded by the residential sector (COPEL, 2013); and by the *diesel consumed by public transportation*, which accumulated 27,002,508.03Km traveled in 2013 (CMTU, 2013). Considering an average consumption coefficient of 0.33 l/Km (Oliveira, 2004), therefore the annual diesel consumption by the urban buses would sum up to 8,917,444.14 liters.

Method

A literature review addressed concepts such as the urbanization process of Brazilian cities; the ecosystem approach; eco-cities; urban metabolism; smart and green mobility; public mass transportation systems; and energy issues within urban planning. Next, an empirical research process aimed at diagnosing the current state of affairs regarding existing mobility systems, energy consumption and the new zoning plan proposed for Londrina. Surveys and interviews were carried out with official governmental municipal departments, such as: the City Hall of Londrina, IPPUL (Institute of Research and Urban Planning of Londrina) and CMTU (Transit and Urbanization Municipal Company).

Computation of the current and future residential energy consumptions, as well as of their renewable energy generation potential, was accomplished through a mixed 'top-down' and 'bottom-up' approach, combined with an 'indirect quantitative relational methodology of data constitution'. The starting point was to create a typology table (Figure 2) based on the categorization of the 12 main residential building typologies (existing and future) extracted from the City Zoning Plan (Figura 1c).

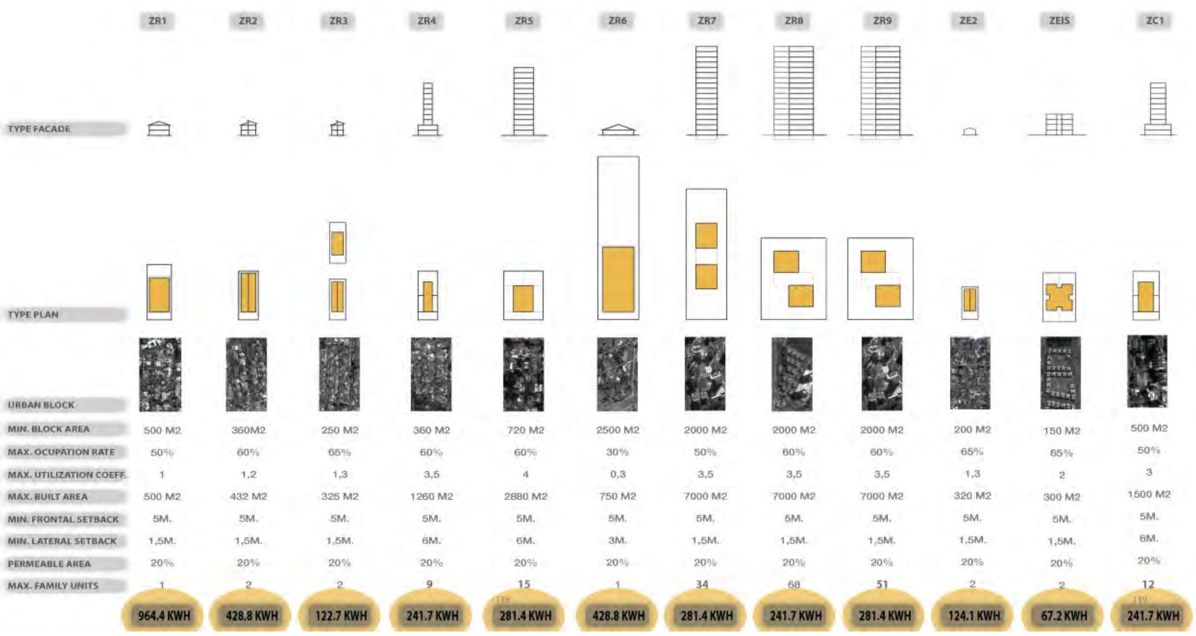

Figure 2: Typology Table with Energy Consumption by family Type

Since the currently enforced zoning legislation (Figure 1c) forecasts zone types for the complete (future) urban limits, an urban void map (Figure 1b) was created using Google Earth to distinguish areas already bearing the future zone type from those yet to be occupied. Both maps were combined over a GIS platform. The area occupied by each zone - and corresponding percentage relatively to the total urban area – allowed to finally infer the total number of families these areas could support. 'In loco' analysis of a number of chosen typologies coupled with information collected from the Parana Electricity Company (COPEL) directed categorization per social class, quality and quantity of electrical appliances and then divided into seven energy consumption ranges (Table 1).

Table 1. Energy Consumption Ranges

TODAY	Total Annual Consumption (MWh)	Total Number of Families per Consumption Range	Average Consumption per Family per Year (MWh)	Average Consumption per Family per Month (KWh)
Consumption Range 1 (0 - 100 KWh)	37428	46432	0.81	67.17
Consumption Range 2 (101 - 150 KWh)	62997	42326	1.49	124.03
Consumption Range 3 (151 - 215 KWh)	94898	44692	2.12	176.95
Consumption Range 4 (216 - 280 KWh)	77977	26,880	2.90	241.74
Consumption Range 5 (281 - 340 KWh)	45748	13547	3.38	281.42
Consumption Range 6 (341 - 580 KWh)	65295	12,689	5.15	428.82
Consumption Range 7 (> 581 KWh)	45631	3,943	11.57	964.39
Total	429974	190509	2.26	188.08

Estimation of average energy consumption of each type followed a top-down approach. From the number of household consumers, the 2013 annual energy consumption (MWh) and the percentage and number of families of each urban zone, we defined consumption ranges and estimated the average monthly consumption/family in each zone. Once we estimated the future number of families for each typology, we projected the corresponding energy consumption, considering full occupation of its urban perimeter.

Roof surface for each zone typology was calculated. The renewable energy generation potential assumed (1) that 300 Wp PV panels would be installed on 10% of the residential buildings' roofs; and (2) a global tilted irradiation value of 5,30 KWh/m^2 (Pereira, 2006) and manufacturer's data. Average energy generation capacity (KWh/month/panel) was multiplied by the maximum number of panels that each typology could hold and summed to estimate the city overall generation potential. Finally, included the massive local renewable energy production (MassREP), composed by the proposed solar farm and linear PV arrays along the two main highways that cross the city.

Results and Discussion

Our calculations showed that, when the whole urban perimeter of Londrina is occupied by its existing and future zoning types (always considering the most densified situation), the city would have about 688,286 family units, whose residences will consume around 1,743,926 MWh/yr.

Installation of PV arrays for distributed energy generation in 10%, in average, of the residential roof surface would produce 1.75 times the overall residential consumption. If PV generation along the *two main highways* that cross the city is added to that of a *power plant* suggested for the northwest future industrial zoning void (Figure 3a), Londrina would be able to also supply a new renewable electricity mobility system. This system could be composed by different public transportation vehicles types (e.g. regional train, light rail, tram) and be combined to walkable streets, slow mobility network and bike highways, ICTs and other solutions, connected by fifteen intermodal terminals fairly distributed throughout the city (Figure 3b).

Figure 3: Proposed (a) energy and (b) smart mobility masterplans for Londrina

Conclusion

Londrina holds a huge potential for solar PV generation and many additional eco strategies due to the combination of economic prosperity, strict enforcement of construction regulations and favorable solar radiation potential. Energy and smart mobility masterplans were developed to express the main guidelines for distributed solar generation throughout the city, allied to an intermodal electricity-efficient public transportation system.

Socio-economic and political aspects are in the very foundation of transitioning towards eco-city models, and become more challenging in developing countries contexts. Financial and structural difficulties for installing PV systems, particularly in low income areas; safety concerns that currently hamper public transportation use and car sharing; and prioritizing green policies such as tax incentives for acquiring PV systems coupled with construction regulations to make it mandatory are some of the issues that need to be addressed for this change to happen.

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Resilience, Aging and Adapting to Change

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Elderly Support To Inspired Ageing (ESTIA)

Leonidas Bourikas[1], Nick Allott[2], AbuBakr Bahaj[1], John Connelly[3], Stephanie Gauthier[1], Patrick James[1]

[1] Energy and Climate Change Division, Faculty of Engineering and the Environment, University of Southampton, Southampton, UK, L.Bourikas@soton.ac.uk;
[2] NquiringMinds, Southampton Science Park, Southampton, UK
[3] Southampton City Council, Southampton, UK

Abstract: In parallel to major demographic change occurring in societies today, austerity measures in the UK have had a considerable impact on local authority budget including social care for the elderly. This work reports on novel research, which aims to harness the value and the power of sharing economy based on digital platforms augmented by surveys to support elderly people in the UK. The Elderly Support To Inspired Ageing (ESTIA) digital platform aims to help the elderly people achieve independent, comfortable living at their home for longer. The three tools of the project are: (1) A contact/scheduling board where all carers and clinicians can share information; (2) A sensing platform that collects data from the house and the supported person's activity; and (3) An on-demand service through which home care services and training can be commissioned. The ESTIA platform will provide a dynamic, shared-economy (Uber-like) market place for domiciliary care services. In essence, this project aims to provide more efficient care services with less administration cost. Finally, platforms such as ESTIA optimised for individual care, may demonstrate a structured transition from state supported to community supported care. This paper reports on initial analysis and the set-up of the ESTIA digital platform.

Keywords: Elderly support, Sharing economy, Digital platform, Domiciliary care, Independent ageing

Introduction

The EU and the UK are facing a major demographic predicament. The decline in birth rate, changes towards more healthy living (e.g. quit smoking), better working environments and modern medicine have all contributed to an increase in life expectancy (Population Estimates Team, 2016). The inevitable ageing of the current population stirs the discussion about the impact ageing has on different layers of the established social structure and systems.

Older people - persons 60 years or older - have invested a lot of money in their properties and they own a large share of the housing market, accounting for about 50% of the UK projected household growth to 2030 in the UK (Andrews, 2008). It is not a surprise therefore that almost all of them would prefer to stay and age at home instead of moving to care facilities (Barlow & Venables, 2004; Andrews, 2008). For this to happen it is necessary to adapt the current housing stock to the changing needs of their occupants and to also create sustainable communities that will support their well-being (Andrews, 2008). New social housing is typically required to conform to strict "lifetime home standards" but the housing industry is rather unwilling to voluntarily take on changes to their “business as usual” design and construction practice (Barlow & Venables, 2004).

In the period, 2013-2014, local councils in the UK spent £8.8 billion for the care of people aged 65 and over. 4 million people in this age band have care needs but only 850,000 qualify for formal state support. 1.5 million rely on informal carers to support them (BBC News, 2015). In 2011, 40% of the English population aged between 50 and 64 years old was providing between 1 and 19 hours per week of unpaid care (Figure 1). More importantly, the self-health of unpaid carers was found to deteriorate with the total hours of unpaid care they provided (Census Analysis, 2013). Carer stress is one of the main reasons that older people are moved to formal care institutions (Barlow & Venables, 2004). Informal and privately funded care is often misinterpreted by governments as cost free (Lipszyc et al., 2012). It is to be expected however that these 19 hours per week of unpaid care will eventually shift to formal care. This shift, in a region such as Greater London would cost an additional £16,000 a year for each person eligible for fully funded at home, support. In the case of residential care, the same cost would be even higher reaching up to £39,000 a year (UK Care Guide, 2016). It is likely that an increasing number of the informal carers will require health services from the NHS before the age of the 65 and/or they will end up with increased care needs at some point after this age.

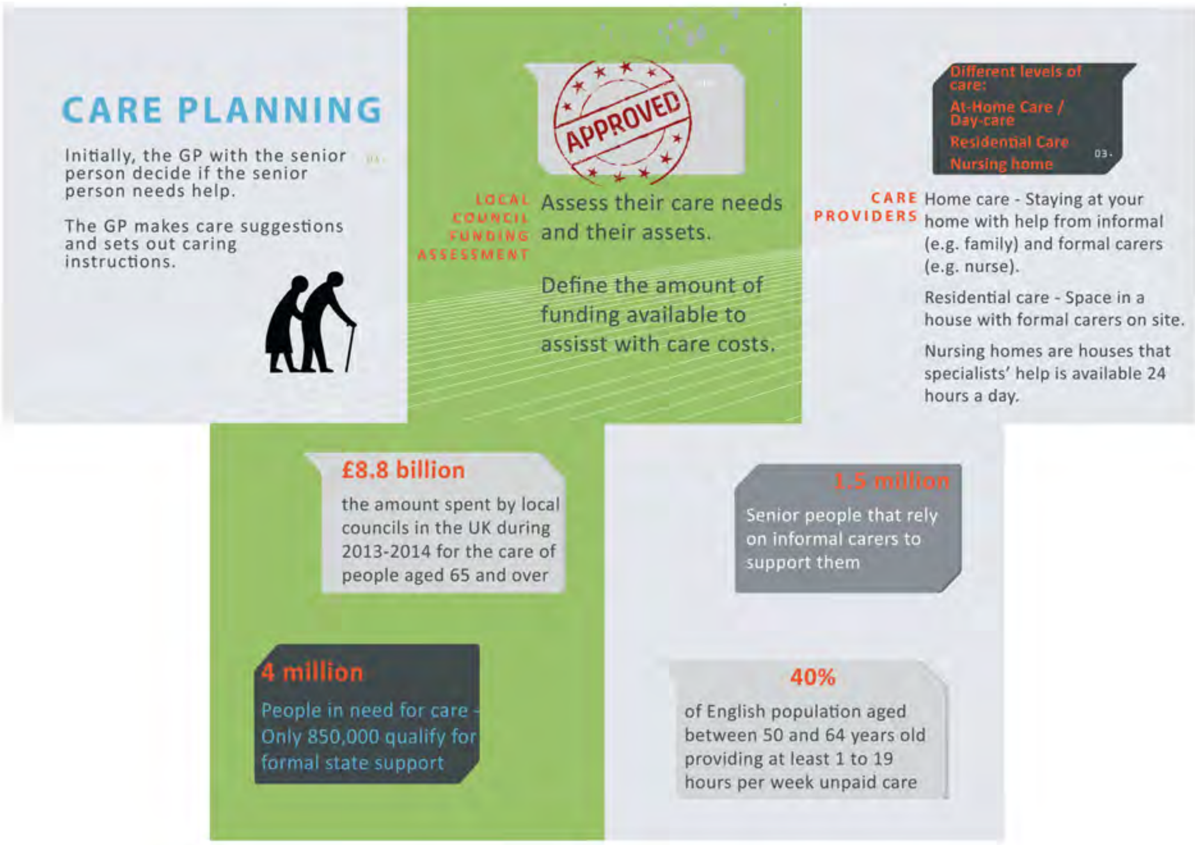

Figure 1. Stages of care planning, cost and market potential in the UK. Data references in text.

In April 2020, a £72,000 cap will be introduced on the lifetime private expenditure for care. In addition, anyone with private assets below £118,500 will be entitled to some sort of care subsidy or funded care from local authorities (AgeUK, 2017). This new policy will give more people access to different levels of formal care (NHS UK, 2015) putting more pressure on local authorities' social care budgets. This budget is further strained by increases in the fees asked by home care providers. Home care providers usually employ staff on an hourly basis and pay them the minimum wage (Jarrett, 2017). The introduction of the 'national living wage' led to a £0.80 per hour wage increase (from £6.70 in 2015 to £7.50 in 2017 (UK Government Digital Service 2017)) for 40% of the home care employees (Jarrett, 2017). In addition, the profit margins of the care providers are also affected by a nationwide shortage of nurses. To cover their nursing demands, care providers are currently hiring agency staff at much higher pay rates (Jarrett, 2017). The increasing cost of care services, the shift of more people from informal to formal care and the support for the elderly currently in private funded care (they usually pay higher prices than the fees negotiated by councils) will challenge the viability of home care providers. Part of the increases in cost will need to be passed down to the customers; in this case, local councils with budgets already under great strain.

The research questions may be formulated as follows: Can a digital platform based on a sharing economy paradigm extricate elderly care support from rigid, high cost care plans? More importantly, can it promote independent, comfortable living for longer?

This paper argues that the development of a digital care platform can tap the social capital (e.g. neighbours, family) and enable informal carers to integrate their resources to achieve enhanced patient centric care. When it comes to formal care and traditional health providers, digital technology should not be seen as a competitor. It can be a useful tool for physicians and home care providers that will enable cost effective residential care and flexible care plans customised to the real time needs of their "clients".

The Elderly Support To Inspired Ageing (ESTIA) digital platform aims to support and promote independent living for the elderly by integrating three critical features in an easy to manage dynamic care platform:

(1) A contact/scheduling board where all carers and clinicians can share information, keep notes, raise concerns and create reports about the wellbeing of the supported person;
(2) A sensing platform that collects data from the house and person's activity and creates profiles of daily routine, alerts and proposals to the person of interest and its carers;
(3) An on-demand service through which the person and family can seek telehealth services, get advice through physicians or commission home care support services and training.

Approach

Tele-health platforms were the first to set an example of an "Uber" like, health related sharing economy application with real time on-demand services (Miller et al., 2016). The benefits for practitioners are flexible working hours and an increase to their income while people in residential care will pay competitive market prices for personalised advice from the comfort of their homes (Miller et al., 2016). The challenge however is to traditional care providers that need to be proactive and adapt their operations to the emerging telecare market rules (Miller et al., 2016). The first steps toward this direction have been made with care agencies piloting a system that enables them to talk through the television set with the person in need. The new emerging market, if it is properly regulated has the potential to lower the cost of formal ad-hoc residential support services, helps informal carers to cope with their tasks and allows elderly people to live at their houses for longer.

Health care platforms learn from the sharing economy paradigm of telehealth but their main advantage is the full integration and inclusion of the social capital. The success of such platforms would be to re-enable vulnerable and socially isolated people in need for care to be part of larger community schemes that have access to advice and care services. From a market perspective, care digital platforms such as ESTIA can provide the means to involve charities and volunteers and take some work away from the carers (Figure 2). Informal carers could benefit from having fewer responsibilities, less stress and access to guides and training. Formal carers will have the opportunity to restructure their services and optimise the use of their capacity and income. Most importantly, it is a significant opportunity for social care policies to include non-directly paid services and integrate them with the paid packages to achieve cost-effective, high value care plans.

Several approaches and efforts have been made to facilitate active ageing, promote social inclusion and provide tools for assisted living for the elderly (Grguric et al., 2010). Most of the efforts focus on the development of smart house applications and on house technological-fixes and sensor packages (Rocha et al., 2013) that send alerts, reminders and prompts and track activity profiles (Libal et al., 2009). ESTIA taps on the experience of existing Ambient Assisted Living (AAL) technologies and moves towards transforming the environment of Electronically enhanced Assistive Technology (EAT) (Barlow & Venables, 2004) into a sociable, interactive and dynamic people-centric care platform. The ESTIA digital platform works across different clusters and levels of information from individuals to hospitals and ambulance services. It is designed to introduce innovative ways for the coordination and commissioning of different levels of care services according to the person-specific expectations and requirements for elderly care provision.

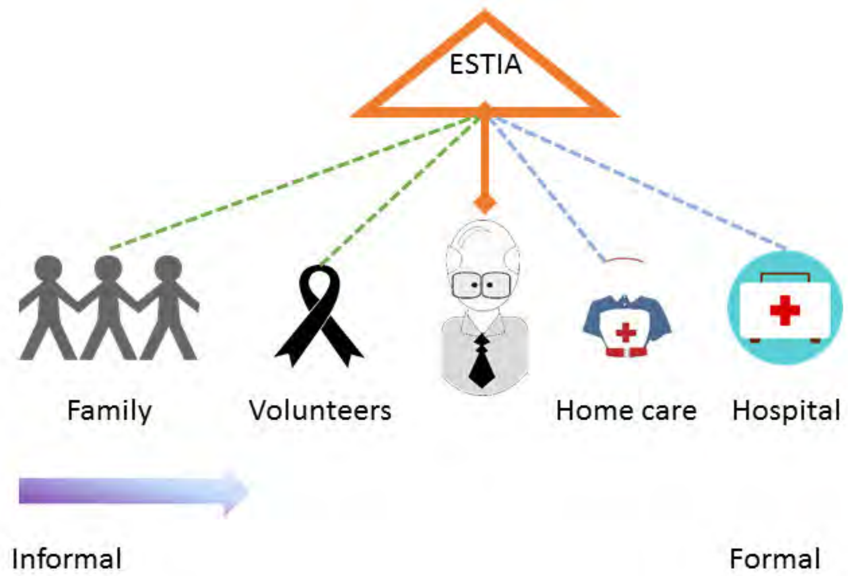

Figure 2. ESTIA platform and its interaction with typical informal and formal stakeholders in the care of elderly people.

The platform has adopted a clustered client based architecture with context aware communications (De Backere et al., 2017) between Communications, Domain and Database cloud servers. It enables multiple implementations of the same simple web interface. The primary objective is to have virtualisations of secure cloud clients running through smart television sets and allow the elderly to browse and access the available services with the remote control of the TV (Figure 3). It has been found however that such web based approaches may result in low response times and loss of services due to incompatible updates and software (Grguric et al., 2010). In order to ensure the flexibility of the system and uninterrupted and wide spread applicability of the services, a second client (e.g. a tablet PC) that runs a local API, standalone application will be installed in the house and it will periodically connect with the scheme's cloud servers. Ideally, there will be a small charging station that has an integrated Ethernet and GPRS connection and the tablet PC that will rest on this hub most of the time. The local API client will be open to communicate with a series of well-tested sensor interfaces and extend its capabilities as a traditional assisted living system such as proactive sensing hubs.

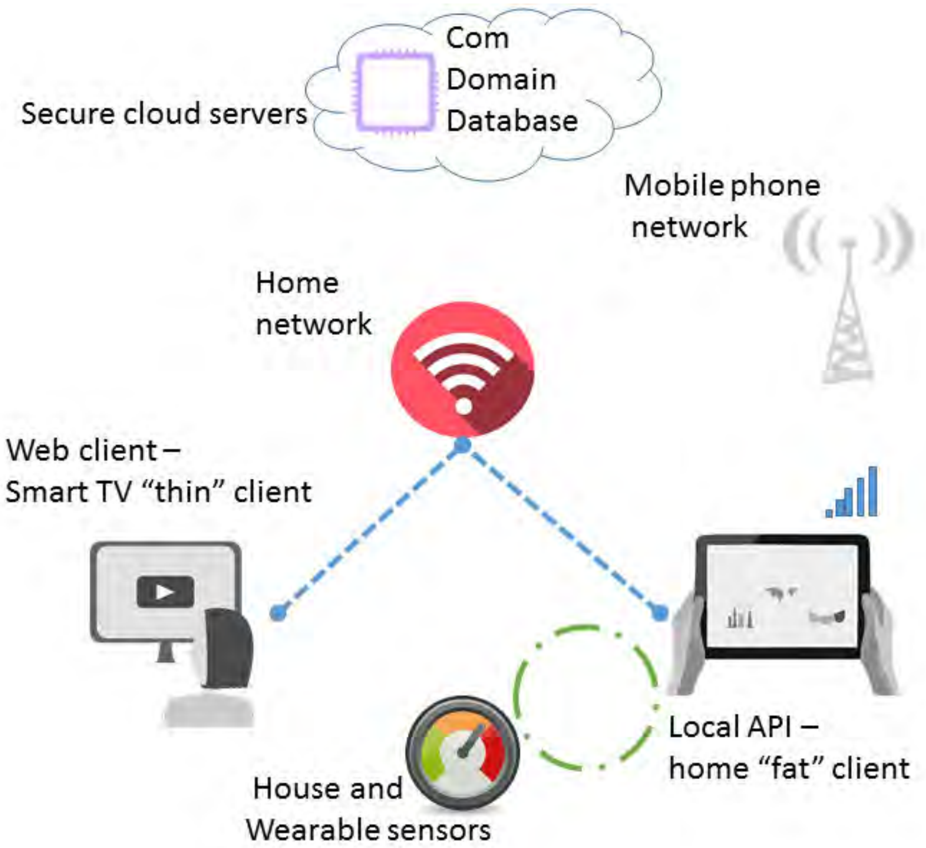

Figure 3. Network layout of the different components and connections of the ESTIA digital platform.

The interface will include three distinct layers of services (Figure 4):

1) The communications board; this board will have menus to access the health records; the care instructions and the care plan details. It will also provide a news feed, reminders about scheduled activities, send message updates to the listed carers and work as a generic chat/forum to share information. The board will support video and sound communications. It could also support video and sound monitoring services (with a function similar to baby monitors) if the people involved consent.

2) The sensing hub; the role of this hub is to allow the integration of passive sensing solutions to trigger "soft" alerts and active sensing to track emergencies and alerts triggered by the person in care. The hub could run from the local client and connect to the GPRS – mobile network. The sensing hub will track the profile of daily and weekly activities and the environmental conditions (e.g. indoor air temperature, carbon dioxide concentrations, etc.) in the house. Any deviations from the representative trend profile of the person in care will

flag events / warnings to the carers listed in this service. The warnings will also appear as prompts in the communications board.

3) The guidance and advice portal; the portal is a third layer of information and training services that can work as an electronic library. The library will contain instructions and advice for the carer and the person in care. Videos and interactive material can be part of the library. The training material can include exercise advice for the elderly and games that can help them stay mentally healthy (e.g. puzzles). This layer will integrate any on request tele-health and tele-care services and it will ideally be activated and navigated with voice commands.

Figure 4. Different layers of services accessible through the ESTIA interface

Challenges and conclusions

One of the biggest challenges of this project is the data governance and the framework for data sharing. This issue needs to be regulated and clearly define the rights and obligations of all digital services and their users. Confidentiality and data protection are paramount. It should be clearly defined who needs the information and what information the different stakeholders require. Different teams and individuals produce and demand different types and levels of data. For example, activity logging may be of value for the family. Medication administration and nurse services are of interest to formal care providers. It is important that all the people involved in the care of a person understand and consent to the use of any available services. The consent of the individuals and confidentiality have a growing importance as people envision and try to move towards smart cities with monitoring of all daily activities, identification of personal behaviours, "detection" of possible emergencies and targeted personal communications (Paolini et al., 2016).

One of the biggest dangers is the replacement of invaluable personal forms of care with impersonal technology features (Barlow & Venables, 2004). The social context and background of a senior person are critical to support his engagement with the community and avoidance of isolation.

Now there are several layers and structure of help from different teams with separate budgets. Community agents and charity organisations can train, coordinate and guide local networks of volunteers. A single point is required to gather information and coordinate the services to tailor help in a "personal sphere" context. This single point -“navigator” will be able to link statutory organisational bodies with private and social organisations.

We believe the biggest barrier to achieve the maximum engagement in the care of the elderly and high-level integration of the social capital resources is personal liability. Informal carers are stressed and they do not want to take responsibility of making decisions for the people they care for. The acuteness of a medical condition is very difficult to be assessed and the “safest response” is to look for health services from hospitals or formal care providers. Digital platforms could have an active role by providing a fast, reliable, first contact point for advice. Emergency tele-health service in combination with sensed data and the help of informal carers could reduce the events when senior people use the ambulance, emergency room or 15 minute response care services. In addition, training material (e.g. videos) and instructions could reduce the carers’ stress and make it easier to maintain a healthy, organised daily routine for the senior person. Exercise instructions, diet advice and mental health games can all promote the senior people’s wellbeing.

Lastly, the medical background and information about the person who needs care at the moment are segmented pieces of information and data spread across a variety of archives and secured with different levels of access. Formal carers would greatly benefit from having the health records, medication plans, care instructions and the care plan in a single source online repository.

The successful implementation of the ESTIA platform and its longevity are entwined with the macro economy of the emerging market ecosystem. Primary focus is given to addressing problems that can deliver the maximum value. We identify that fast, enhanced communications and information sharing is crucial for the successful development of any care-share application. All the stakeholders have an important role to play but it is the informal carers – the social capital that mainly needs to be engaged, trained and supported in order to be actively involved in peer-to-peer care support. We recognise the monetary but mostly the intangible value of this resource. Lifetime homes, ageing neighbourhoods and cities, social structures and market, all have direct and collateral benefits from caring for the elderly to keeping them healthy, active and happy at home for longer.

Acknowledgement

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Resilience and older people: My home my life

Catherine Bridge

Enabling Built Environment Program, Faculty o the Built Environment, University of Sydney, Sydney, Australia, C.Bridge@unsw.edu.au

Abstract: There are both challenges and opportunities for urban design and housing regarding the uptake of 'livable home' design. in the context of both an ageing population and a greater likelihood of major weather events and global warming impacts. There are a number of key factors that shape the way that 'livable home' design in Australia has been developed and adopted. For instance, there has been insufficient policy attention paid to home modification or housing retrofit so as to ensure that older peoples housing is capable of substituting for community care and facilitating the option to age in place. This was a very real issue in 2011 when devastating floods over 75 per cent of Queensland caused great distress for many older people and meant many were unable to remain at home. Additionally, the lack of integration of climate and accessibility features potentially creates a triple jeopardy situation with older people being more vulnerable due to both climate events, physiological factors and increased likelihood of living in poorly adapted homes. This highlights the social and environmental injustice involved, in reflecting on the structural and attitudinal impediments that need to be addressed for housing form to increase the resilience of older people.

Keywords: Population ageing, home modification, climate change, urban density, lifetime design.

Introduction

Bringing together climate change and universal design principles for ageing has become a critical challenge for older people, urban planners, housing and infrastructure policy makers alike. The policy mantra is that everyone would be better off in smaller homes; and in denser suburbs, so as to facilitate less natural resource usage and greater public or active transport options. But what does this mean for 'ageing in place' and life quality for our burgeoning older population in Australia. Indeed, there appear to be a multitude of overlapping or contradictory standards that are applied to housing both at the design stage and in terms of its adaptive reuse. Part of the problem appears to be that, older people, designers and local government have quite different ideas about what is necessary, usable and comfortable. This is despite the fact that the core concept of sustainability concerns not just conservation of natural resources, but social good and economic viability over time. The problem in balancing and integrating sustainability dimensions stems from the primary focus resting on ecological concern with social sustainability being less valorised. Further, housing developers and builders are not responding to the needs of older people as they say there is little or no demand (Nishita, Liebig, Pynoos, Perelman, and Spegal, 2007). This view is reinforced by research that found that new buildings were no more likely to be accessible than those built in the mid-1990s (Chan and Gould Ellen, 2017).

A critical driver is density. For example, Australia is one of the most urbanised Nations in the world and Sydney the city with the largest population has recently established minimum lot sizes as low as $125m^2$ for housing in its middle ring to curb suburban sprawl (Department of Planning New South Wales, 2016). Smaller lot sizes and minimum frontages for dwelling houses and dual occupancy dwellings are required to improve sustainability and affordability but there is an inherent tension as those on aged pensions are the very people most likely to benefit from better integrated design and planning solutions. The failure of differing design and policy agendas to coalesce is of critical import given the large and increasing proportion of Australians who are over the age of 65 years and who are ageing within the increasingly fragile and unpredictable Australian climate ecosystem. For instance, summers are now longer and hotter and with a resultant increase in extreme weather events including flooding, extreme heat and longer fire seasons.

Importantly, a detailed report on the impacts of climate change on coastal areas of Australia, found that up to 247,600 houses were at risk from flooding from a sea-level rise of 1.1 metres (Department of Climate Change, 2009). Older people represent a significant group not only in numbers but in terms of housing ownership and financial resources available to choose their housing composition. As they experience the typical effects of ageing they can become more vulnerable to difficulty or injury due a climate change combined with reduced income and a lack of supportive features in housing design placing them in triple jeopardy. Unfortunately, the needs and desires of older people are underrepresented in the climate change debate and to a large part in sustainable home design initiatives. This indicates a potential for more integrated practices and presents possibilities for innovative products to be developed through careful understanding of the issues involved.

In January 2011, Brisbane, Australia, experienced its first significant flooding in almost four decades, this brought the tensions between 'livable housing' and climate extremes to a head. The findings from Brisbane are similar to those found in other post-disaster research and many Brisbane residents stated their surprise at the impact of the flood and even that such a flood could occur (Box, Bird, Haynes & King, 2016). Additionally, the limitations that underlying social vulnerabilities such as age and low income can present to flood preparedness left many at risk and the resultant criticism of government preparedness and actions left no appetite for widespread implementation of initiatives such as 'livable housing' in new build as it was at odds with the traditional Queensland flood and climate solution a raised home (Kennedy, Hockings, & Kai, 2005).

Changing demographics

Population ageing is expected to have implications for aged care and health, size of the working age population and housing (ABS 2016). In line with trends in other developed countries Australia's population is ageing due to increasing life expectancy and continuing low fertility (AIHW 2014b). Life expectancy by 2013 was 80 years for men and 84 years for females, indeed the proportion of Australians aged 65 and has risen from 12.0% to 15.3% between 1996 and 2016 (ABS 2014a). Critically the proportion of people aged 85 and older is projected to continue reaching 5% of the population in 2061 (ABS 2013). Growing older often comes with limitations and the financial sustainability of care services is already causing concern. Thus moving healthcare and social-care services into the homes of older people is attractive, especially given modern technologies such as home automation that can be used to create an innovative living environment. Universally designed housing within Australia is increasingly being badged as 'livable housing' a concept that blends universal design intent with that of other initiatives such as sustainability. Livable housing design is intended for everyone and should be a part of all new build, but unfortunately it is still predominantly viewed as being primarily for those people with a disability.

A smart home on the other hand is a home capable of responding to an older people's needs and activities by compensating for and/or adapted to reduced cognitive and physical ability. In the case of both the 'livable' and the 'smart' home, there is an inherent tension in regard to ecological sustainability. This is because of the increased expense and the need to retrofit. For example, removing internal walls to increase circulation spaces for wheeled mobility can decrease energy efficiency ratings, while automatic environmental controls and air conditioning also increase energy load and costs. The 'livable housing' design guideline's concern housing with as few as six simple design features, such as reinforced bathroom walls, a flat entry to the house and wide corridors and doorways. The fact that livable housing and ecological sustainability are poorly aligned, results in a failure to address the home as a vessel to provide protection to a more vulnerable occupant at times of extreme climate events such as prolonged hot spells or in floods. Indeed, there is little or no consensus regarding the definition of universal design features or of those critical to ecological sustainability and thus the use of concept such as provision of level access a core component of 'livable housing' are continuing to prove problematic as the rest of this paper sets out to demonstrate. The current lack of integration of these concepts, runs the risk of bringing less accessibility, safety and comfort to older people.

Home modification: consumer survey results

Level access is an sustainability adaptation concern given the fact that traditional housing design has included stairs at entries to prevent flooding, but stairs can be a barrier for those with limited mobility, assistive device users and a tripping hazard and fall risk for older people more generally. An exploratory research survey regarding home modification uptake and outcomes was mailed to all consumers who received a home modification organised by Hunter New England Area Health Service in New South Wales, Australia upon discharge from hospital in 2011. Consequently, three hundred and ninety-five health clients were invited to complete the home modification survey. Eighty-three surveys responded to the question concerning the type of modification, this response rate representing a response rate of twenty-one per cent, a good response for a postal questionnaire targeted at an older population. The donut graphs (below), shows that many of the respondents required an access modification to help them in moving through the home (70%). This is unsurprising given the voluntary nature of 'livable housing' design in Australia.

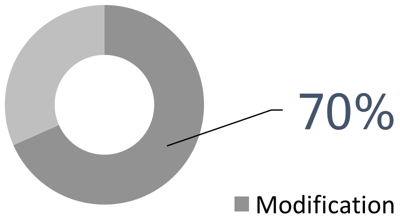

Figure 1. Access modifications required as a proportion of all home modification interventions undertaken in the Hunter New England Area Health Service upon discharge from hospital in 2011.

The relationship between caregiving and design is important as design may not only support care-giving but substitute for it. For instance, found that design directly substituted for care (Carnemolla, 2015). Informal care was the most sensitive, with reductions in care forty-one per cent for moving about the house but the greatest reduction was in formal care. These results clearly indicate that care is sensitive to design with a forty-seven per cent overall reduction in the care provided. This is a significant finding given previous research, compared costs for people care in various housing settings with those receiving residential care identified that where care can be provided in the home, the cost saving to government is significant (Bridge, Phibbs, Kendig, Mathews & Cooper, 2008).

Flooding events and level access

The most frequently cited argument against level access is around flooding and drainage strategies. These issues are traditionally overcome in 'livable housing' with the addition of cover. The entry design most often promoted for new build of single dwellings provides a level access via the carport as illustrated in Figure 2.

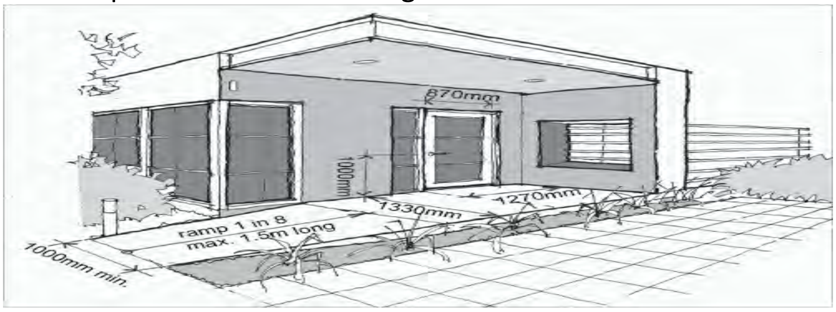

Figure 2. Level entry design (Palmer& Ward, 2013).

Nevertheless, qualitative responses to this same survey revealed that water ingress and slipping may not be ameliorated or even fully addressed after home modification interventions as this survey respondent says "*We found that the covering over our car port (ramp is under car port) is inadequate and we now have rain coming up on ramp - very dangerous at times*" (respondent 33, home modification follow-up survey)[1]. Where the risk of water pooling increases as in tropical climates where large volumes of water fall in a very short period or where only limited side and roof coverage is provided, then consideration of lipless or level drainage channels with accessible grate are also necessary. Figure 3, illustrates one such relatively low technology solution known to effectively reduce the risk of flooding and water pooling.

Figure 3. Drainage grate to prevent water ingress

Another advantage of the design afforded by an integrated roof and sidewall extension is reduction in the risk of flooding and/or water pooling on very wet or windy days. This is because water falling on the roof will be carried off by a standard guttering system and

[1] The sampling frame for this exploratory research survey was all consumers who received a home modification organised by Hunter New England Area Health Service in New South Wales, Australia upon discharge from hospital in 2011.

because the overhang is sufficient to prevent wind driven rain penetration. However, the more traditional covered porch solution where sides are unprotected as in Figure 4 is less effective in reducing the risk of wind driven rain penetration.

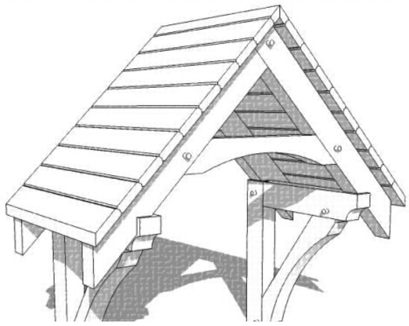

Figure 4. Door canopy to prevent water ingress

An underutilised but more climate friendly design in areas prone to flooding or likely to have significant water ingress is an earth berm and bridge entry design. Such a design consists of a retaining wall and walkway graded at a slope of 1:20 or less up to the entry level. A level bridge, in combination with a deck or porch, spans the distance between the retaining wall and the building entrance. The "moat" thus created enables rainwater drainage away from the building and can be filled with gravel or suitable plant specimens (i.e., plants for wet areas).

Importantly, landscape modification can successfully overcome inaccessibility, reduce modification cost and make for a less stigmatising and ecologically sustainable outcome in some if not all residential homes (Carnemolla & Bridge, 2012). The feasibility of modifying the residential landscape is determined not only by the type of homes, in particular the building's relationship to the streetscape, but also site features including available land area, existing site, vegetation, topography, hydrology and soil conditions. For instance, research conducted by Chan and Gould Ellen (2017) found that homes within buildings with more than fifty units were found to be more accessible than those with less units, reflecting the lack of an elevator in smaller multifamily units.

Despite these specific limitations, where landscape modification is considered a technically feasible access solution, it brings with it a number of benefits in addition to providing immediate access between garden path and front door. Landscape modification can be designed to sensitively blend with existing architecture, thereby maintaining perceived house values and reducing stigma. an underutilised alternative access solution to ramps and lifts. Findings such as these require additional research examining the comparative costs of accessible landscape modifications, consumer responses to landscape modifications and examination of current industry practices and skill base in order to better integrate sustainability objectives within a community care and 'livable housing' policy framework.

Housing and income

Older homeowners want to age in place and this decision making relates to their housing location, which reflects connection to community and proximity to services (AIHW 2013; Boldy et al. 2011). But most people are best placed financially around retirement age to make changes to their housing configuration of their own choosing that will support them in the longer (AIHW 2013; Quine & Carter 2006; Productivity Commission 2011). However, there is a strong tendency to avoid planning for retirement and ageing (Olsberg & Winters 2005). Unfortunately, the majority of ageing Australians do not have sufficient superannuation to support themselves through retirement and will be dependent to varying degrees on the age pension (Malcolm 2012). However, the ease with which a property can be structurally modified to support either sustainability or ageing in place, can be traumatic especially where issues of title and finances are problematic (Ward et al. 2012). Additionally, there is evidence that Government supported home modification schemes are underutilized by eligible people (Bridge & Gopalan 2005). This may be due to complexities in the application and eligibility process or individuals not perceiving a need in their environment, choosing instead to adapt their behaviour to cope (Bridge, Phibbs, Gohar, & Chaudhary, 2007).

While financial resources could be made available through refinancing the family home there is a reluctance to do this unless absolutely necessary (Bridge, Adams, Phibbs, Mathews, & Kendig, 2011). Additionally, the design and construction industries are insufficiently prepared to deliver 'livable housing' let alone accessible housing that is ecologically and economically sustainable for a vulnerable lower income population. The value of age-friendliness in renovation or new building projects is not always obvious to the public or to older homeowners, and clear guidelines for the execution and financing of such projects are scarce, so targeted action and greater investment is much needed (Ruddock, 2016). The absence of a National regulatory framework has resulted in a plethora of approaches; creating confusion and undermining universally designed housing as a viable option for older people wishing to age in the same locale (Bridge, 2012). Lastly arguments and lack of government incentives, have traditionally been perceived as a barrier to more widespread implementation of both sustainable and universally designed housing features.

Conclusion

Failure to understand the interaction of inclusive design elements with those that better protect vulnerable older people in the face of extreme weather events such as fire and flooding are a missed opportunity. These are significant contributors to the quality of a dwelling and the risk is that living environments will be degraded without them. If more inclusive design practices such as routine consideration of level entries are viewed from a more integrated sustainability and climate change perspective, their value becomes obvious not just in regulatory compliance for public buildings but also in injury prevention and in improving ease-of-use and efficiency for all building users. Human comfort is a concept that embraces and potentially unites diverse aspects of both 'livable housing 'which is trying to achieve accessibility, usability, adaptability etc. and ecological sustainability which is trying to achieve better thermal comfort, humidity and air quality etc. Design for sustainability is a complex issue involving several complex processes and integrating 'livable housing' design as a methodological extension for sustainability is challenging, but failure to address it in a timely manner will compromise not just quality of life for older people but add significant additional economic and ecological burdens to societies with ageing populations.

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Designing Housing Decision-support Tools for Resilient Older People

Bev James[1] and Kay Saville-Smith[2]

[1] Director, Public Policy & Research Ltd, Wellington, New Zealand, bevjames@xtra.co.nz
[2] Director, Centre for Research, Evaluation and Social Assessment (CRESA), Wellington, New Zealand, kay@cresa.co.nz

Abstract: Critical to maintaining independence as we age, is the ability to make informed decisions about challenging questions concerning housing choices, dwelling performance and resilience, and residential movement. Over the last nine years the New Zealand-based GoodHomes research teams have worked with older people and community organisations to investigate issues around housing, ageing in place and resilient communities. Out of that participatory research has evolved evidence-based decision-support tools to help older people maintain independence. All tools have been co-designed and tested in homes and in charrettes with older people and with service and housing providers supporting older people. These tools help older people identify priorities and information requirements, as well as assess the diverse factors involved in home-related decisions. These decisions encompass not only the dwelling, but also the neighbourhood and physical environment, health and support needs, social connections, resource needs and constraints, and cultural preferences. The tools are: The Good Home Tool for home repairs and maintenance assessment and solutions; the Resilient Homes Tool and Selecting a Site for Your Home Tool enabling better dwelling and location choices; and My Home, My Choices, a decision-support toolkit for making housing decisions.

Keywords: Ageing-in-place, Housing, Resilience, Decision-making, Participatory design

Introduction

Homes that are warm, in good repair, can weather adverse events and enable residents to move around safely are crucial to ageing well and enabling older residents to stay living independently in their communities. It is well known that older people are potentially more at risk or vulnerable to harm from adverse natural events, such as storms, floods, bushfires, land erosion, coastal surges and earthquakes. In normal times, too, the home can pose a threat to safety and wellbeing. Poor home repairs and maintenance can exacerbate older people's vulnerabilities to harm in good times and bad (James and Saville Smith, 2010). Equally, poor choices by older people around the siting and design of the dwelling they live in can expose them to both risk and expense. Housing that fails to meet older people's needs reduces their personal resilience and independence, but there has been little attention given to building age-friendly, resilient housing in New Zealand or enabling older people to make good housing choices.

This paper reports on three research programmes focused on how older people's resilience can be supported and increased, despite inadequacies in the New Zealand housing stock and a pattern of under-performing and under-maintained housing often sited in vulnerable environments. Those research programmes incorporated three important elements. First, they were committed to understanding the experiences and perceptions of older people within their built environments. This involved using a range of research methods: surveys, interviews and focus groups. Second, the research was multi-disciplinary bringing social scientists, natural hazard scientists and building technologists together. Finally, the programmes were solutions focused and oriented to enabling older people. This was accomplished through explicit, purposeful and participatory design activities involving older people themselves directed to developing evidence-based decision-support tools. During the latter phase of tool and solutions design in each programme, older people reviewed research findings and technical knowledge.

Four of the tools generated by those research programmes are reviewed here. They are: Good Homes, Resilient Homes, Selecting A Site for Your Home, and My Home, My Choices. All tools are found on the website www.goodhomes.co.nz. The paper firstly examines 'older people' and 'vulnerability'. It then describes the research activities, the key findings underpinning each tool, and describes the tools. Then the participatory design approach is discussed. The last section comments on the usefulness and impact of the tools in supporting older people's resilience and choices.

Older people, vulnerability and ageing well

While the population aged 65 and older is diverse in health and disability status, living arrangements, financial and housing circumstances, older people can be particularly vulnerable to poor housing conditions. Cold and damp housing can cause or exacerbate illness such as respiratory problems, asthma, hypertension, and coronary and cerebral thrombosis. In New Zealand people aged 65 and over are especially vulnerable to excess winter mortality, which is higher than the European mean. Levels of heating, thermal performance and indoor air pollution have all been suggested as contributing factors to this excess mortality (Davie et al, 2007). Dwellings in poor repair, or lacking in accessibility features can cause injury, which in turn leads to premature entry into aged residential care (Bridge et al, 2006). There is also considerable evidence that older people are more vulnerable to natural hazard risks and this can be exacerbated if their housing is not robust enough to protect them. Older people are more likely to die, be injured, or to worsen chronic conditions during or after adverse natural events (Greenberg, 2014; Carswell, 2010; AARP Public Policy Institute, 2010). In part these vulnerabilities are due to age-related frailty, declining health or physical impairments. Also, other factors, such as financial constraints, reliance on others for transport, the extent of connections to local supports and services, and living alone affect vulnerability.

The Research Programmes

The three research programmes at the centre of this paper are: *Ageing in Place,* which addressed the role of poor house performance and the burden of repairs and maintenance; Community *Resilience and Good Ageing,* which investigated how older people can be supported to help themselves and their communities to manage and recover from adverse natural events; and, *Finding the Best Fit,* which focused on the realities, costs, risks and benefits of downsizing for older householders.

Ageing in Place

This multi-method research included surveys, interviews, dwelling condition surveying and a systematic review of repairs and maintenance programmes targeted to older people. The research found that owner-occupiers aged 65 and over were even more likely than other age groups to under-invest in repairs and maintenance (Saville-Smith et al, 2008). Even if they could pay, older people often delayed repairs and maintenance. They often over-estimated the costs of repairs and were frequently overwhelmed by managing the process of procuring repairs and maintenance. They also under-estimated the impacts of failing to undertake repairs and maintenance. The components of older people's houses that were in worse condition than the dwellings of younger householders were: inferior ceiling insulation and poorer condition of windows, roof claddings and steps/ramps. These components are implicated in cold, damp and unsafe dwellings. Using these findings, the *Good Homes Tool* was developed to support older people to be more confident and prepared to assess their home repairs and maintenance needs and to identify a range of solutions, so that they can maintain their homes as safe and comfortable places.

Three versions of the tool emerged; a 'self-help' tool for the older householder, a version for providers of social and support services, to check that their older client's home is safe and in good repair, and a technical version for owners or managers of housing for older people. The householder and service provider tool is in the form of a booklet consisting of a checklist and solutions covering key components inside and outside the dwelling, e.g.: outdoor and indoor lighting; pathways; ramps and steps; decks/balconies; roofs; walls; windows; piles; doors and handles; floors and coverings; ceilings; plugs; hot water; heating. Components are assessed room-by-room, e.g.: kitchen, bathroom, bedroom.

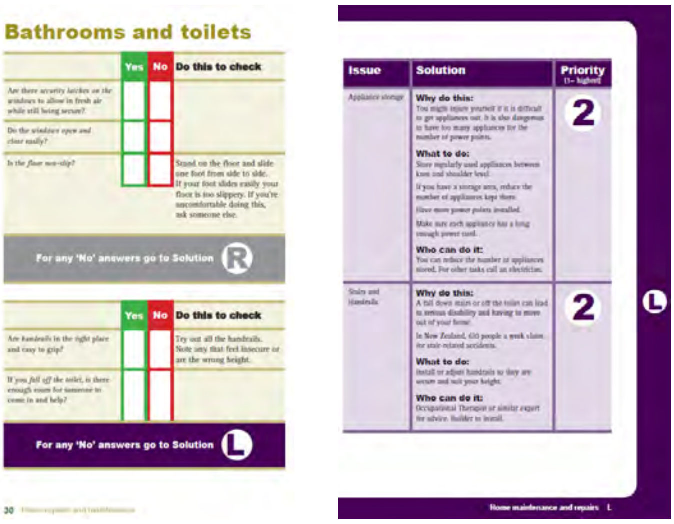

Figure 1. Good Homes Tool: Part of Bathrooms and Toilets Checklist

The tool helps to identify repairs and maintenance that need to be done, safety issues, the best person to do the work (e.g. if a registered tradesperson is needed), and the priority of the job. The tool is written in plain language, with step-by-step instructions. Diagrams and pictures illustrate technical terms where required. The tool encourages older householders to feel confident about assessing their home by explaining that the room-by-room assessment can be done as time permits, and with the help of a friend. The technical version for housing providers and property managers provides a robust set of home diagnostics. This tool comprises a hardcopy and an accompanying electronic spreadsheet, which prioritises the work, providing solutions to remedy each issue as well as indicative costing information.

Community Resilience and Good Ageing

This multi-method programme included a national survey of 631 people aged 65 and older who had experienced an adverse natural event, hazard risk mapping, analysis of councils' emergency management documents, in-depth interviews with 28 older people affected by floods, and focus groups with over 110 older people living in natural hazard-affected communities. The research found that an adverse natural event can be a 'tipping point' for an older person to remain living independently. Damage to house or property, or having to move residence, are likely to increase older people's needs for support, decrease their sense of wellbeing, and potentially make them worse off financially (Saville-Smith and Fraser, 2013). Research participants, while reporting stress and disruption, also reported that they learned new skills and gained confidence in managing challenging situations, and made contributions to the preparation for, and recovery after an adverse natural event. However, they were critical of a lack of information about emergency preparation tailored to older people's needs, inadequate inclusion of older people in emergency planning, and poor information to enable older people to make informed choices about residential sites, resilient building design and materials (James and Saville-Smith, 2014).

Two tools were developed. The *Resilient Homes Tool* provides guidance on identifying dwelling design, materials and systems features that pose a risk in storms or floods. The guide covers roofs, skylights, verandahs and decks, windows, walls and wall cladding, exterior doors, wiring and electrical systems, as well as resilient lighting, heating, cooking and water features. The *Selecting A Site for Your Home Tool* enables a quick assessment of a residential site and provides information about where to find out about site vulnerability to natural hazards. The guide covers wind, flooding, landslides and changing land use.

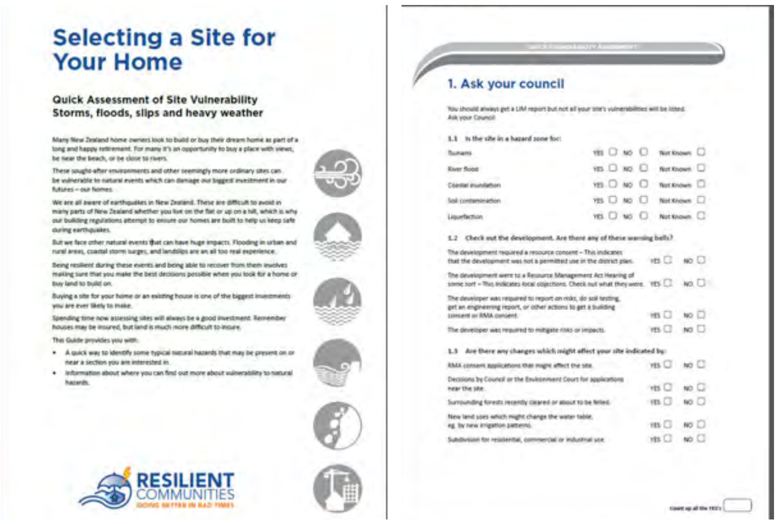

Figure 2. Pages from Selecting a Site for Your Home Tool.

Finding the Best Fit

This multi-method programme included regional housing market analyses, a national survey of 571 people aged 65 and older, a survey of 617 retirement village residents, and interviews and focus groups with over 220 older people and over 70 providers of services for older people. The programme found that for most who downsize, the amount of equity release is modest, if any. This is because the supply of small, affordable dwellings is constrained, and most people move within the same housing market. Furthermore, often realised equity is used to deal with debt or everyday living costs (Saville-Smith et al, 2016).

Clear housing preferences were expressed for a home that maintains independence, is warm and easy to maintain, easy to move around in, affordable to buy or rent, has cheap running costs, is compact but has sufficient space for activities and visitors, is close to services and has an outlook (Saville-Smith and James, 2016; James, 2016a). Participants identified a wide range of information needs about dwelling price, location, tenure and amenities. They also sought information about services supporting people in their homes.

My Home, My Choices was developed in response to concerns about poor information provision. It is designed to help older people identify what is important about their home environment, and decide whether to stay in their current home, to make changes to their home, or move. The tool is available in both hard-copy and as an interactive website. The tool describes over 60 options, including advantages and disadvantages of each option. Individuals can work through the tool at their own pace and compare different options. The 'answer' is not provided, instead suggestions are made about where individuals can find information on the issues and options they wish to investigate.

Figure 4. My Home, My Choices Tool: Hard Copy and Web Version

These three research programmes found a strong desire among older people to be actively involved and to maintain control over decisions around their housing and home-related needs. The programmes also found that older people as consumers did not have sufficient, relevant and impartial information, either to know the range of options available to them or to make informed choices (James et al, 2016; James, 2016b). The programmes identified similar challenges for older people. First, home-related decisions are complex. It is not only about whether to stay or to move. It is also about household products, dwelling materials, natural hazard risks. location and support services. Financial implications need to be understood, as does whether a decision taken now has long term implications that could limit future options. Second, information sources tend to be fragmented, sometimes confusing and not easy to access. There is poor coordination across different agencies and sectors. Third, it is difficult to access impartial information in some areas such as housing products, services and materials, and information is seldom available in age- and disability-friendly formats.

Participatory design approach

The three programmes used a participatory design approach, which is not only about actively involving older people in the research process underpinning tool development, but also about meaningful engagement in design and testing of tools (Spinuzzi, 2005; Bridge et al, 2016; Dewsbury et al, 2006; Haak et al, 2015).

All tools were designed, developed and tested over several stages, outlined below. Participants assisted in various ways at all stages. Older people hold important knowledge through their life, community and work experiences. Their knowledge, lived experiences, needs and aspirations were valued and used. Participants' pre-occupations, concerns and priorities were of primary importance in guiding the tool development, so that the tool is relevant to the user. Participants were pivotal to identifying both the problems and the solutions that resulted in the tools. There were mechanisms for participation that allowed people to iterate the tools, through workshops/charrettes, as well as local and national advisory groups. Furthermore, participants tested the tools in their homes or applied them to real-life situations and provided feedback, which was essential in improving the relevance and user-friendliness of the tools.

A range of participants were involved so that different experiences were drawn on to test the tool's usefulness and applicability in various situations. Across the three programmes, people aged in their late 50s to early 90s participated, including people with disabilities; those living alone, as a couple, or with younger family members; and living in large urban areas, provincial towns and rural locations. The majority were owner occupiers, although some in licence-to-occupy units and rentals also participated.

Brainstorming and prototype development

Testing research findings and brainstorming ideas for tools was done in feedback sessions with those who participated in the data gathering stages. The researchers had not formed a fixed idea about tools that might be developed. Instead participants were instrumental in generating ideas. The idea for a 'checklist' to help older people manage their home repairs and maintenance came from participants. Older people in the *Finding the Best Fit* research wanted a tool that would help them find information to support their decision-making about their home-related needs. The idea for the two resilience tools came from participants' interest in information that would have helped them to better identify natural hazard risks. Many believed they had exercised due diligence when they bought their property, yet there were risks they were unaware of (Saville-Smith, 2014).

Older people were less involved in prototype development. After the brainstorming, the researchers undertook tool development, based on the research findings and participant feedback. Prototype development of the *Good Homes Tool* was led by a building scientist, supported by other research team members. The two resilience tools were developed through workshops with experts in natural hazards, engineering and building technology. There was considerable debate among those experts about how to compile guides for the lay person, and the several prototypes produced reflected those tensions. A hard-copy prototype of *My Home, My Choices* was developed by the research team through a review of five overseas tools to help older people assess their housing situation and explore housing options, and a workshop with an expert advisor.

Testing the tools

The *Good Homes Tool* went through several iterations. An early version of the householder tool was trialled by three older people in their homes. An early version for experienced housing assessors was workshopped by staff of a community housing provider. Feedback from both trials was used to improve the tool designs for trialling at three charrettes, where participants worked through the tools in detail. Charrettes included older people, health and social service providers, older people's advocacy groups, repairs and maintenance providers, housing providers, councils, Māori organisations, church groups, and service clubs. After revising the tool in response to charrette feedback, over 150 older people used the revised tool by themselves at home, or were helped by a service provider to use the tool. Eight housing providers tested the tool on their properties. Written feedback from those testers was used to further refine the tool.

The challenge for the two resilience tools was to ensure that the technical guides were easily understood and relevant to the needs of older householders. Three workshops with older people were used to test the prototypes developed by the technical experts. Their responses resulted in considerable rewriting of both tools, to make them simpler to understand, with more pictures, and an easier check list to record potential hazards.

The hard-copy version of *My Home, My Choices* was tested with over 100 people in eight workshops. Older people, health and social service providers, older people's advocacy organisations, housing providers, Māori organisations and policy agencies were among those involved in the testing. Over 80 suggestions were received from the tests. Over two-thirds of those suggestions were used to refine the tool. The interactive web tool was then developed from the hard-copy and tested by six older people. Based on their feedback, further adjustments were made to the tool.

Positive impacts

All the tools were designed for, and with the active involvement of, older people living independently in their communities. Their contributions to tool development show how research can facilitate older people's participation in building their own and their community's resilience. The research shows, too, how solutions-focused investigation can address the persistent information asymmetry found within the design and delivery of the built environment.

The tools are having a positive impact in helping older people to make informed choices, to plan and to take action. Evidence for the impact of the *Good Homes Tool,* which has been available since 2012, is most apparent. This tool has been picked up by over 50 organisations. Implementation pathways through local organisations and media as well as national bodies, resulted in six national stakeholders placing the tool on their websites or referring to it in publications, dissemination of the tool to older residents by three councils, use of the tool by three neighbourhood regeneration / repairs and maintenance programmes, endorsement of the tool as a way of reducing falls at home, and one district health board (DHB) integrating the tool into its public health programme. The DHB evaluated the tool and found a high level of interest among volunteers supporting older residents to use the tool, as well as older householders themselves. Overwhelming feedback was that the tool was useful. Householders identified jobs to do, both immediate and planned. Some used the tool to talk with tradespeople about needed repairs, and tradespeople reported that the tool improved clarity of communication with clients. Jobs completed included painting of steps, cleaning out gutters and water pipes, making a fire/emergency plan, checking and installation of smoke detectors, repairing ranch sliders, installing hand rails and pruning overgrown trees. Service providers noted their clients' confidence in managing their home had improved through using the tool.

Interest in the two *Resilience* tools, launched in September 2014, has been mainly from organisations concerned with improving dwelling quality, such as the Building Research Association of New Zealand, and community housing providers. The *My Home, My Choices* tool was launched in August 2016. To date, around 150 tools have been taken-up, mainly by organisations, including councils, local Age Concern offices, Māori health providers, Iwi organisations, Community Advice Bureaux, an organisation supporting older people to age-in-place, local budget advice services, legal services and financial advisors. Training sessions in using the tool have been provided by the researchers.

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Sustainability and Resilient Homes for the Older People in Natural Adverse Events

Roman Jaques[1] and Kay Saville-Smith[2]

[1] **BRANZ, Building Research Association of New Zealand,** Roman.Jaques@branz.co.nz
[2] **CRESA, Centre for Research Evaluation and Social Assessment,** kay@cresa.co.nz

Abstract: Resilience has become the 'new black' among policy advisers, practitioners, researchers and academics. From individuals to cities, organisations to buildings, and industries to ecosystems, questions are being asked about their ability to function, adapt and perform well in the context of changing circumstances and when subjected to significant shocks. This is concerned with the intersection between resilience and sustainability and its implications for older people. It explores the current knowledge base around the performance of the most fundamental of components in the built environment – dwellings. Specifically, dwellings designed to be sustainable in the context of adverse natural events. It shows that, while there is an overlap between some elements that are sustainable and those that are resilient, frequently the characteristics of what have become accepted as sustainable are assumed to deliver resilience as well. Key ways in which the sustainability and resilience of dwellings can be enhanced to protect older residents during adverse natural events, reduce the damage likely to be caused by adverse events, and assist the recovery process subsequent to adverse events, are examined.

Keywords: Ageing, resilience, sustainability, adverse events

Introduction

Resilience and sustainability are the 'new black' for policy advisers, practitioners, researchers and academics (Wingfield *et al*., 2006). Broadly the concept of resilience refers to the ability to adapt to, perform during, and regenerate from adverse events. By contrast, sustainability refers to the ability to function in the long term by minimising the importation of resources from 'outside' the system and the impacts of the system on the environments in which it operates. From individuals (Bencze and Tilotta, 2010) to cities (Peng *et al*., 2012), from organisations (Building Seismic Safety Council, 2006) to buildings (Mejia, 2008), from industries (Bowker *et al*., 2007) to ecosystems, questions are being asked about their ability to function, adapt and perform well in the context of changing circumstances and, in particular, when subjected to significant shocks. Across the natural, physical and social sciences as well as in public policy, questions are being asked about the factors that protect in the context of adverse events and the pathways and mechanisms that encourage successful adaptation. Those questions become especially important in countries experiencing ageing populations, especially where older people, as they are in New Zealand tend to be housed in areas vulnerable to adverse natural events such as river and coastal flooding, coastal surges and storms (James and Saville-Smith, 2014a; Bell and Wadha, 2014).

For older people concepts of resilience and sustainability can appear abstract. Yet all older people have an interest in homes that protect them during adverse events and also provide them with comfort and amenities that minimise resource use and costs. In the New Zealand housing market there is increasing emphasis on the sustainability of houses and the use of accreditation tools such as HomeStar and LifeMark. The question that arises is whether sustainable homes are also resilient homes. This paper explores the current knowledge base around the performance of dwellings designed to be sustainable in the context of natural adverse events. It shows that, while there is an overlap between some elements of sustainable homes and resilient homes, the assumption that sustainable homes are resilient homes is largely untested. Moreover a careful review of features promoted respectively as sustainable or resilient shows misalignment between the two. This paper identifies ways in which sustainability may be brought together to protect older residents during natural adverse events, reduce the damage likely to be caused by adverse events, and optimise the recovery of the dwelling itself and the daily lives of older people subsequent to those events.

Sustainable Homes and Resilience

Despite the widespread branding of homes as sustainable, 'green', environmental, 'earth-friendly', 'off-grid', or 'eco' there are no formalised definitions. In New Zealand, the Beacon Consortium coined the term NOW Home® (Beacon Pathway Incorporated, n.d.) for dwellings that could be delivered into the mid-price housing market while simultaneously minimising water and energy consumption, and materials and operating waste, and maximising thermal performance. The New Zealand Green Building Council is accrediting homes under its HomeStar system (www.homestar.org.nz). Other countries show a similar plethora of nomenclature around sustainable dwellings. None of these labels are entirely synonymous, typically they refer to dwellings designed, built, operated, maintained or re-purposed to significantly enhance the dwelling's lifetime environmental performance.

Performance in those domains is purposefully prioritised compared to existing homes and new homes delivered through the mainstream building industry and increasingly, accreditation tools are used to signal a sustainable home. Those tools are very diverse in their mechanics, ranging from the very simple checklists specific to a particular region through to the very complex and comprehensive international green building frameworks. An example of the former is 'Build it Green' (www.builditgreen.org), designed for use in Oakland, California. This contrasts with the International Initiative for a Sustainable Built Environment (IISBE) SB Method and SBTool (www.iisbe.org) which has a global approach. One of the very earliest formal green building assessment methods, BREEAM (www.breeam.org), was introduced by the UK's Building Research Establishment (BRE) in 1990. Through its approach, BREEAM became a template for many other international tools that followed, such as LEED from USA and Canada (www.usgbc.org/LEED), DGNB from Germany (www.dgnb.de/en/), CASBEE from Japan (www.ibec.or.jp), and HomeStar from New Zealand (www.homestar.org.nz). The domestic assessment version of the scheme – BRE Global EcoHomes – has now morphed into the Code for Sustainable Homes (BRE, 2013) which is mandatory for all newly built homes in England and Wales. More recently, comprehensive, consortium-driven sustainable building guidelines and standards have emerged, such as the 2012 International Green Construction Code (ICC, 2013).

Despite their diversity, sustainable homes accreditation tools all tend to focus on similar domains, themes or parameters: energy, water and material efficiency; thermal performance; protecting occupant health; reducing waste; and environmental protection. The idea that sustainable homes will be resilient homes able to endure and recover from adverse natural events largely resides in the emphasis in sustainable homes on reducing the import and export of resources. Broadly, accreditations for sustainable dwellings are framed around two considerations. The first is the quantity and sustainability of the resources used to build and maintain the dwelling. The second consideration is the systems associated with living in and operating the dwelling. In most sustainability accreditation systems, where the expected consumption and import of water and energy is minimised, dwellings are likely to score higher on the sustainability measures included in the accreditation. This is also the case where the export of waste and external impacts are minimised. Dwellings with off-grid energy generation, independent sewerage, on-site stormwater management or on-site water collection are typically placed very highly by sustainable homes accreditation systems. Figure 1 shows how HomeStar provides credits along what might be broadly described as a sustainability continuum.

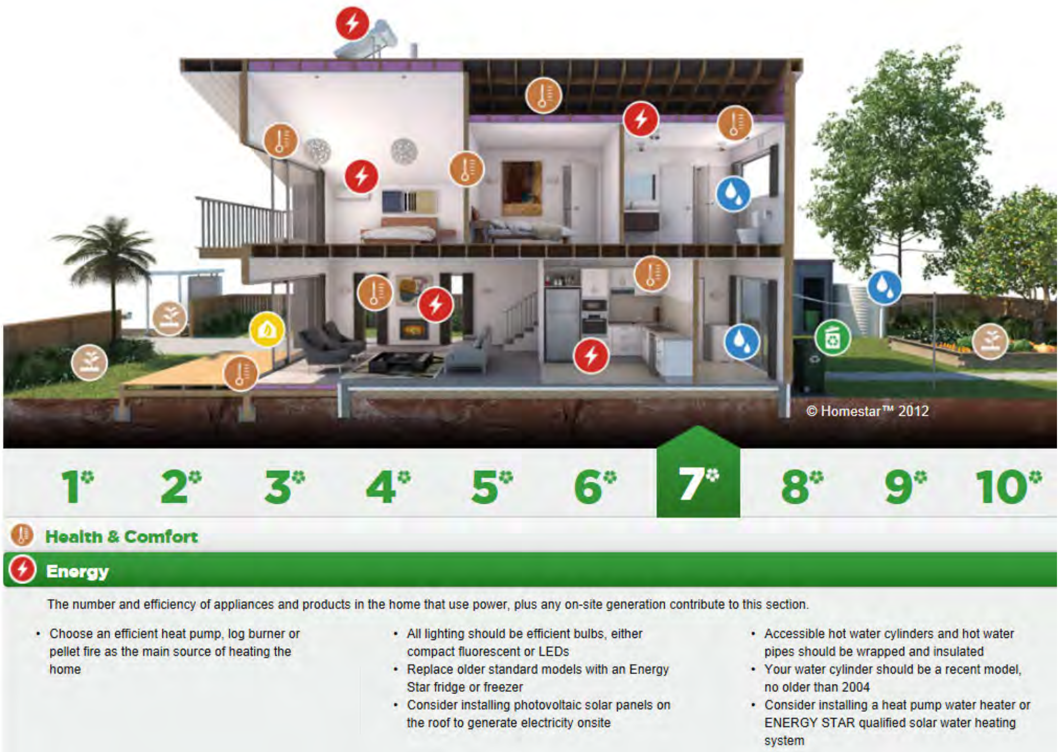

Figure 1: HIGH END SUSTAINABLE BUILDING (Source: www.homestar.org.nz)

This 'hardware of independence', which tends to detach dwellings from centralised and attenuated infrastructure, often leads to assumptions that sustainable homes are resilient homes. However, few of the sustainable homes accreditation tools actually incorporate a robust concept of resilience into their assessment procedures. Those that do tend to do so only cursorily or have a very narrow focus. Take for instance, the UK's Code for Sustainable Homes (CSH), which makes accreditation dependent on attention being given to flood risk. The accreditation tool provides for detailed drainage system design calculations, flood risk and consequential impact assessments to be undertaken. Resilience to other adverse natural events are given only cursory consideration.

Accreditation tools for sustainable homes do make opportunistic connections with resilience. Take for instance, the Portland Cement Association and the Institute for Business and Home Safety (IBHS) which have a sustainable building standard entitled the *High Performance Building Requirements for Sustainability (*Szoke *et al*, 2010). Written in mandatory language amending and appending to the *International Building Code* (ICC, 2009), there are claims that the sustainability features enhance disaster resistance and set more stringent durability requirements. Indeed, the then director of the IBHS claimed that "using these requirements will give forward-thinking communities not just more efficient buildings, but more sustainable communities that have the ability to resist and recover from disasters when they occur" (PRWeb, 2010).

In reality, considerable uncertainty exists around the extent to which the sustainability 'hardware' results in delivered resilience benefits. Three issues arise. First, the durability and functionality of independent micro-systems such as energy generating technologies under adverse conditions. Second, there is the issue of whether they deliver to the critical needs of individuals during and after adverse events. Third, there are questions as to whether sustainability hardware and materials encompass the critical elements of sustainable dwellings that are likely to protect, reduce damage and facilitate recovery among residents. Much of the reporting about the performance of sustainability technologies under adverse conditions has focussed on the durability of products. There appears to be little reporting of their functionality during and after adverse events, or the costs of recovery.

Some data is available; for example, William Young has presented case studies around photovoltaic panels which show high rates of survival. Of 20 systems located in the Florida hurricane pathways, only three were subject to damage and the damage was minor (Young & Haggard, 2006). Similarly, Hurricane Charley, which struck Charlotte County, Florida, particularly fiercely in 2004, left 25 of 32 monitored solar systems both undamaged and operational (Young, 2005). There is, however, a notable silence in the literature about how functional these technologies were during and in the recovery period subsequent to an adverse event in terms of the actual delivery of light, comfort provision and cooking. Examples of practices promoted in green buildings which clearly pose resilience challenges include: vegetated roofs providing additional dead-loads, and the use of roof-mounted photovoltaic systems creating extra wind loading.

There are, of course, some features of dwellings that achieve credits in homes rating schemes that clearly provide positive value to both the resilience of the dwelling and its household. For example, minimising impervious surfaces allows for better stormwater management, while appropriate berm arrangements (Gromala, 2010) allow for level entries necessary for people with compromised mobility to evacuate their dwellings if necessary. Similarly, the installation of properly secured and substantially-sized water tanks has positive impacts for both the sustainability and the resilience of a dwelling and its household. In relation to sustainability, water tanks reduce the waste of potable water when non-potable water is required for gardening and cleaning. In relation to resilience, water tanks provide stores of water useful for firefighting. They also provide a source of relatively uncontaminated water which can be made potable when water supply infrastructure fails in floods or earthquakes. Nevertheless, the failure to map resilience actions for adaptation to hazards is illustrative of the considerable gap between the approach to and measurement or rating of sustainable dwellings and the issue of actually delivering resilience.

Resilience through Fortified Dwellings

Resilience primacy is at the core of the FORTIFIED (www.disastersafety.org/fortified/) building movement, launched in 2010 in the United States by the Insurance Institute for Business and Home Safety (IBHS). It is a voluntary, national programme aimed at incorporating building techniques into both residential and commercial construction to provide a higher level of protection against a variety of natural hazards. FORTIFIED Home^{TM} operates as a third-party verification programme designed to help homeowners strengthen it via a tailored evaluation, inspection, and retrofitting process, to meet the challenges of specific, regional natural hazards. Hazards addressed are: flood, interior fire and water damage, earthquake, wildfire, high wind, and severe winter weather. In 2008, the initiative was battle tested by Hurricane Ike on the Bolivar Peninsula in Texas. Thirteen FORTIFIED homes survived a direct hit from the hurricane, including a 20-foot storm surge (Peng *et al*., 2012). These 13 homes were the only structures left standing in the immediate vicinity. It was postulated that their specific design feature to withstand extreme wind and water damage was the reason for this durability.

Unfortunately, details on the FORTIFIED homes' post-event functionality, in terms of service provision and comfort, are sparse. They are only described as having been 'left standing'. This leaves unanswered a myriad of questions. Were the buildings habitable? Did they provide a reasonable level of utility for their occupants? What was the resulting condition of the affected building materials? Did recovery require subsequent replacement of materials? What was the degree of remediation required? Was there a strong relationship between the designation level of fortification and the resulting utility post event? Little details around these questions appear to be provided in the public domain. Similarly, there is little detail regarding the costs of builds, the operating affordability or the amenity and comfort provided by these buildings to occupants prior to an adverse event.

It has been claimed that the most sustainable buildings will also be the most resilient buildings – "a truly disaster resistant building would be a zero energy home or building that ensures a high level of energy security…" (Young & Haggard, 2006, p. 4). The reality is, however, that the vast majority of 'zero energy homes' are no more likely to be able to provide added energy-based utility post event than more traditionally powered homes. Apart from the issues of the durability of the hardware previously noted, the vast majority of renewable systems in the 'western hemisphere' are grid-intertied photovoltaics. These are very unlikely to have any energy storage capability, mainly due to the very high purchase costs of batteries. In addition, for safety reasons, in an event, once the network goes down so too does the in-house electrical system, whether the solar system is generating or not. As Terry Brennan has stated in regard to the claimed resilience of buildings off-grid and on-grid: "If they lose only electricity, few buildings in the U.S. can provide as much comfort as my backpacking tent" (Wilson, 2011).

Sustainability, Resilience and Older People

In a sense, the debates about what precise sustainability solutions generate increased resilience do not matter for most of the older people of today. Much of the design and build work directed to sustainability or resilience is embedded in the new home market. Older people typically live in dwellings built prior to either the preoccupation with sustainability or the preoccupation with resilience. Most older people are confronted with dwellings deficient in both sustainability and resilience. At the same time, however, many older people are very vulnerable to adverse natural events. They are more likely to be frail or disabled that other members of the community and so the consequences for them of dwellings that fail to protect them during an adverse event or are difficult to restore subsequently can be profound. In addition, older people, in New Zealand at least, are often located in areas vulnerable to adverse natural events such as storms and flooding. Indeed, older people often select vulnerable, and sometimes isolated, landscapes near beaches, rivers or on elevated sites with views on retirement (James and Saville-Smith, 2014a). Coastal modelling in New Zealand clearly shows that older people are over-represented among the population vulnerable to coastal inundation (Bell and Wadha, 2014). The proportions of people aged 65 years or more at risk of coastal inundation can be considerable. Eight regions in New Zealand have in excess of 15 percent of their older populations living in coastal elevation zones of less than 3 metres (Figure 2).

Figure 2: Proportion of over 65 year olds living in costal elevation zones of 0-3 meters for selected regions

The vulnerabilities of already fragile sites can be expected to increase in the context of climate change and older people can be expected to bear the burden of those changes. In 2050, it is forecast that New Zealand will have 1.35 million older people. A million of them will live in settlements at risk of severe adverse natural events (Wright *et al.*, 2011; Smart and McKerchar, 2010; Walton *et al.*, 2004). The impacts can be profound for older people. Research in New Zealand (see http://resilience.goodhomes.co.nz/) and elsewhere (Cornell, *et al.*, 2012; Whittle, 2010) show that adverse natural events become a 'tipping point' between independent and dependent living. Older people's ability to care for themselves and participate in their communities is closely associated with the familiarity and comfort of an older person's home surroundings. Once home is disrupted, even for a short period, it can mean a decrease in the ability to live independently. Older people's incomes are often constrained and easily drained by the expenses associated with temporary accommodation, repair and remediation even where insurance is adequate. Community connections become attenuated and sense of belonging and home can be distorted (James and Saville-Smith, 2014b). The private and public costs, consequently, of older people's losses, including their loss of independence, can be considerable.

Unlike younger people, older people do not have time in their life course to 'make-up' what has been lost. For older people, then, resilience has three aspects. The first is protection during an event. The second is the ability to stay well and survive the immediate post event conditions which might see them isolated from others in their own community or their communities isolated from services. The third, is restoration – the ability to repair their homes and, often, their gardens and resume a more normal life. Those imperatives require a different sort of integration between sustainability and resilience to that seen to date. If older people are to access the benefits of sustainability and resilience, they need solutions to the challenge of retrofitting their existing homes, not simply accreditation of new builds. They need to understand their current vulnerabilities and be provided ways to protect themselves including options such as: designs for affordable garden swales to reduce flooding or fire risk; ensuring safe areas within dwellings which can be kept cool or warm in extreme temperatures; cooking and lighting; and, independent water supply and options for waste disposal when reticulated or other options are not available. Older people investing in new builds or moving home need to be enabled to understand the risks around site selection as well as the resilience of the building materials, designs and amenities they may choose for their homes. Most importantly, older people as well as designers, developers and builders need to understand the relationship between the 'kit' that is presented in the market as sustainable and its resilience under adverse conditions.

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Population Ageing, Housing and Resilience in Australia

Bruce Judd

City Futures Research Centre, Faculty of Built Environment, University of New South Wales, Sydney, Australia, email b.judd@unsw.edu.au

Abstract: Population ageing is an international phenomenon with major implications for economic and social policy, and for housing and urban planning. A common policy response has been to encourage ageing in place by increasing levels of support in the home, to reduce burgeoning health and aged care costs and enable older people to remain for as long as possible in their home and community. However, this begs the question: ageing in what kind of place? In the long-standing family home, relocating to a more suitable dwelling, or in an age-segregated retirement village? In Australia, there are popular conceptions about ageing and housing which deserve to be questioned: that older people underutilise their dwellings, should downsize, and prefer to live in age-segregated retirement communities. Such stereotypes however do not stand up to empirical scrutiny. This paper draws on three research projects conducted over the last decade into how older Australians utilise their homes and neighbourhoods, their moving and downsizing behaviour, and multigenerational living, to address these perceptions from the perspective of resilience. It concludes with suggestions as to how the resilience of ageing Australians might better be supported through appropriate housing, planning and economic policy and improved industry practice.

Keywords: ageing, housing, resilience, Australia

Introduction

Population ageing is one of the most important social changes in the 21st century, though occurring at varying rates in different countries. Japan leads the world in population ageing with 33.1% of its population aged 60 and over in 2015, having grown by 9.0 percentage points since 2000, and expected to increase to 40.9% by 2050. Italy, the oldest country in Europe had 28.6% of its population 60 and over in 2015, predicted to grow to a similar 40.7% by 2050. The UK (23.0%) was close to the European average of 23.9%, and Australia was a little lower with 20.4% of its population 60 years and over, predicted to reach 28.3% by 2050, (UN, 2015). This presents many challenges to governments, placing stresses on the economy due to increasing dependency ratios (i.e. population 0-14 and 65+ to those 15-64), a reducing tax base, and increasing health and aged care costs (Productivity Commission, 2015). Australia, like many other countries, has introduced policies to address this including changes to the pension eligibility age and asset tests, compulsory superannuation, and encouraging ageing in place and community care to ease pressure on the demand for residential aged care. Accordingly, there has been a progressive increase in the level of aged care services delivered to the home, including for dementia care.

However, the emphasis on ageing in place begs the question: ageing in what kind of place? Most Australian dwellings are not considered suitable for ageing in place and attempts to introduce age-friendly adaptable or universal design for new dwellings have been largely unsuccessful. Even if mandated, new dwellings only represent a very small percentage of annual total dwelling stock, so change would be incremental. It is argued that older people underutilise their dwellings, should move to smaller dwellings and release their larger homes into the market for younger families. Retirement villages are often seen as an ideal solution, yet accommodate only a small proportion of the older population. Multigenerational living is adopted by some older people for financial, cultural, or care and support reasons but is not easily accommodated within conventional housing design. This paper will examine these issues from the perspective of resilience, using evidence from three studies conducted over the last decade. It will examine how housing contributes to the resilience of older Australians, and hence to positive ageing and social sustainability.

Resilience, Ageing and Housing

Resilience is a concept used in both the physical and human sciences. Its origin is from the Latin word *resilire*, meaning 'leaping back' and was initially applied in the physical sciences to materials and objects with "the ability to recoil or spring back into shape; elasticity", but more recently to include humans, being "able to withstand or recover quickly from difficult conditions" (Stephenson & Waite, 2011:1224). In the social sciences, the term has been applied to the ability of individuals and communities to recover from, or thrive in, the face of adversity; in the environmental sciences for species (including humans) to adapt to climate change and natural and man-made disasters; and has also been applied to housing and the built environment in terms of their ability to adapt to climate change, natural and man-made disasters and social change.

The earliest studies of psychological resilience concerned how children thrive despite difficult circumstances, focussing on protective individual personality traits, but has more recently been conceptualised as a more complex process drawing on a range of resources (Fletcher & Sarkar, 2011). It has also been more widely applied across the life span including to those of older age, in view of their exposure to ageing-related risks such as death of loved ones, sickness, accidents, disability, isolation, and so on. The two necessary components of resilience are some sort of risk (or stressor) and positive adaptation (Fletcher and Sarkar, 2011). The interest in resilience of older people reflects the important shift in gerontology from disengagement theory to successful ageing as conceptualised by Rowe & Kahn (1998).

Masten and Wright (2009:215) defined resilience over the life span as "patterns or processes of positive adaptation and development in the context of significant threats to an individual's life or function." However, resilience is not just about individual attributes, but as Janssen et al (2011:146) have noted, "…scholars increasingly acknowledge that positive adaption and development (resilience) is also is also influenced by external factors like families, communities and wider contextual circumstances". While psychology stresses the importance of the social environment as a resource for resilience, the role of the physical environment has also been acknowledged (Golant, 2015), consistent with the importance placed on person-environment (P-E) fit, meaning of home and attachment to place to healthy and successful ageing within the field of environmental gerontology (Ostwald et al, 2007; Rowles & Bernard, 2013).

A recent review of the concept of resilience notes the "overlapping and interrelated scales of household, family, neighbourhood and community resilience" and the different areas of resilience in later life: psychological, mobility, financial, environmental, physical, social and cultural (Wiles et al 2013:150-152), many of which are supported or inhibited by aspects of the built environment. In a review of the concept of resilience, Windle (2011:158) identifies four “layers of resources and assets that facilitate resilience” that include aspects of the built environment: individual, family and household (housing), neighbourhood and social context (environment and transport) and social policies (housing policy).

The role of the built environment as a resource for resilience is also being recognised in ageing and housing policy. A recent report commissioned by the South Australian Government (Windsor et al, 2015:58,59) identifies a “residence better suited to needs”, “better access to transport” and “lived in a better neighbourhood” amongst resources supporting individual resilience, and state that “community resilience often centres on infrastructure or the built environment” (Windsor et al, 2015:58,66). A recent issues paper prepared by the Advisory Taskforce on Residential Transition for Ageing Queenslanders (2016:7,9), identifies both individual and home resilience as important to an “individual’s propensity to explore transition options”, where home resilience includes “…the factors impacting the individual dwelling, such as its design, accessibility, proximity to services and transport, and the age friendliness of the local community”.

The Research Projects

This paper draws on three projects undertaken within the City Futures Research Centre: **Dwelling, land and neighbourhood use by older home owners** (Judd et al, 2010), involving analysis of 2006 ABS Census data, a national survey of 1604 older (55+) home owners administered via the *50 Something* seniors’ magazine, and 70 in-depth interviews in 5 Australian states, funded by the Australian Housing and Urban Research Institute (AHURI) and the Commonwealth Department of Health and Ageing (DHA); **Downsizing amongst older Australians** (Judd et al 2014), involving 2011 ABS Census data analysis; a national survey of 2767 older people who had moved since turning 50, again administered via *50 Something* magazine, 60 In-depth interviews, and policy workshops in 3 states, also funded by AHURI; and **Living together: The rise of multigenerational living in Australia** (Liu et al, 2015), involving analysis of 1996-2011 ABS Census data, an online questionnaire with 392 respondents from 318 multigenerational families in Sydney and Brisbane, 21 solicited diaries from 15 households, and 21 in-depth interviews, funded by an Australian Research Council (ARC) Discovery Grant.

Older Households their Housing in Australia

At the most recent 2011 ABS Census, a substantial majority of Australians 65 and over (84%) were living in either 1 (28%) or 2 (56%) person households, while 71% resided in detached single family dwellings, and 83% in dwellings with 3 or more bedrooms. Only a small percentage lived in attached/row housing forms (9%) and flats/apartments (10%). Even fewer (8%) lived in non-private accommodation, mostly comprising residential aged care facilities. Three quarters of all older Australians (76%) lived in owner occupied dwellings, comprising 67% outright owners and 9% mortgagees (ABS, 2012b), though outright owners have been decreasing in recent decades. Only 5.3% percent were living in retirement villages in 2010 based on industry estimates (Productivity Commission, 2011).

This broad picture of the housing of older Australians raises some important questions regarding housing and resilience. Why do so many persist in living in larger houses on large allotments that are not considered suitable for ageing in place? Do they really underutilise their dwellings? To what extent are they downsizing or moving to more appropriate housing, and why? And what are the ageing in place options that are positive resources for resilience?

Dwelling and Neighbourhood Utilisation

In the Dwelling, land and neighbourhood use study (Judd et al, 2010), analysis of the then most recent 2006 Census data (ABS 2006) found that 83% of Australians 55 years and older lived in 1 or 2 person households, a similar 85% in detached single family dwellings, and 83% in dwellings with 3 or more bedrooms. A similar 84% lived in owner occupied dwellings (either outright or with a mortgage), though outright ownership increased with age from 57% of 55-64 year olds to around three quarters of those in the 65-74, 75-84 and 85+ cohorts. Using a modified version of the Canadian National Occupancy Standard (CNOS), officially used in Australia to measure housing utilisation, a staggering 84% of dwellings of Australians aged 55 and over were deemed underutilised, i.e. with one or more 'surplus' bedrooms. However, 91% of our survey respondents regarded their larger dwellings as satisfactory for their household's needs. This brings into question the mismatch theory, which has also been challenged by previous scholars (Batten, 1999; Wulff et al, 2004).

One important reason for satisfaction with the size of the dwelling was the presence of 'temporary residents' in 25% of respondents' households (i.e. who stayed for at least 20 nights per annum but less than 6 months), not included in the Census household count. Temporary residents included: older children (37%), other relatives (20%), grandchildren (18%), elderly parents (5%) and tenants/boarders (1%). An important reason for maintaining a larger dwelling was the widespread use of 'spare' bedrooms either as guest rooms to accommodate visiting family and friends (27%), or for other non-sleeping purposes such as office/study (34%), hobby (12%), storage (9%), utility (4%) and reading rooms (2%). Some respondents claimed they needed more space post-retirement as they spent more time in the home, and some couples needed their own personal space. Maintaining social ties with family and friends, ongoing personal office or study activities and hobbies are considered important for positive ageing, and are recognised as resources supporting resilience.

A second focus on neighbourhood utilisation revealed the multitude of activities in which older people were engaged. Common daily-to-weekly activities included shopping (95%), recreation (79%), religious services (68%), visiting family and friends (64%), volunteering (58%) and community/social clubs (56%), while the most common monthly-to-yearly activities included medical appointments (92%), theatre and cultural activities (90%) and dining out (58%). Conversely, it was found that poor quality neighbourhood design (paths/crossings, street furniture and facilities, public open space, and transport infrastructure) could present real barriers to community participation. Such activities are also important resources for resilience, and suggest that a supportive built environment extends beyond the dwelling to the neighbourhood and the wider urban infrastructure.

Moving and Downsizing

Given the propensity of older people to remain in their larger homes, we embarked on a following project to investigate the moving and downsizing attitudes and behaviour of older Australians (Judd et al, 2014). Analysis of 2011 Census data (ABS, 2012) revealed that only 18% of older people (50 and over for this study) had moved within this five year period. Based on our survey data, it was estimated that only around half of these (9%) would have downsized (by number of bedrooms). Of these, the majority (71%) relocated to private housing in the general community, and around one fifth (21%) to retirement villages – though this did increase with age from 7% for 55-64 year olds to 54% of those 85 and over. A little less than half (43%) had moved into smaller detached dwellings, 28% to attached dwelling and 23% to flats/apartments, the latter two including those who had moved to retirement villages. The reduction in number of bedrooms was significant, from 3 and 4 bedrooms (42% and 62% respectively) to 2 and 3 bedrooms (47% and 33%) with correlating reductions in floor area.

When asked about the circumstances contributing to downsizing, 'lifestyle preference' (38%) and 'inability to maintain house or garden' (27%) were most commonly cited (38%), with secondary circumstances including 'children leaving home' (17%), 'retirement' (16%), 'relationship breakdown' (12%), 'death of partner' (10%), 'illness' (8%) and 'disability' (7%). Financial difficulties were only rarely cited (6%) compared to 'financial gain' (10%). The concept of 'lifestyle preference' is, however, difficult to disentangle from other factors such as reduced maintenance, retirement, or relocation to a more attractive area. Difficulties with maintenance can also be precipitated by negative shocks.

When looking for their new home, the most important considerations in moving were 'less maintenance of the home' (7(74%) and '…yard' (73%), a 'smaller dwelling' (67%) and once again 'lifestyle improvement' (67%). Location was common amongst second order considerations including 'closeness to shops' (55%), '…public transport' (49%), '…health services' (48%), '…children/relatives' (35%), and '…friends' (30%). In terms of dwelling and neighbourhood characteristics, a 'more accessible home' was important for 38%, 'a more attractive area' for 32%, and 'a more modern home' for 24%. Of the financial considerations, 'reduced cost of living' was cited by one third (33%) of respondents, a 'better investment' by one fifth (19%) and 'to discharge or reduce a mortgage' by only 14%.

When relocating, downsizers sought their information mostly from family (52%) and friends (30%) or real estate agents (27%), less often from financial advisors (14%) and rarely from health/aged care professionals (5%), government (4%) or seniors' organisations (1.2-1.4%). Three quarters (74%) of downsizers found the move either 'easy' or 'very easy', and a quarter (26%) 'difficult' or 'fairly difficult'. The most common difficulties encountered by the latter were 'availability of suitable housing type' (64%), 'cost or affordability' (45%), and 'suitability of available locations' (33%), with less common locational difficulties being 'distance from family or friends' (18%), '…retail facilities' (12%) and '…health facilities' (9%). While cost/affordability was flagged as a problem by close to half, difficulties arising from transactional costs (5%) and obtaining finance (5%) were rare.

Our policy workshops with ageing and housing organisation stakeholders identified three main barriers to downsizing: (1) inadequate supply of smaller, affordable, accessible dwellings located close to services; (2) financial costs including stamp duty, real estate fees, temporary accommodation and removalists fees, housing market fluctuations, and the potential impact on pension eligibility; and (3) psychological and practical barriers including attachment to the home and neighbourhood, and the stress of preparing for sale, decluttering and moving. Other recent research on downsizing (Adair et al, 2014) in Australia found that while 30% of people 50 and over had considered moving to a smaller dwelling, only 10% had done so, the major barriers being the effort of moving and finding a smaller well-priced home.

While for the majority, remaining in a larger home and familiar community appears to support resilience, for those finding maintenance difficult, particularly if accompanied by negative shocks, the dwelling can be a significant stressor precipitating an adaptive response of either home modification or moving to a more appropriate dwelling. However, moving and/or downsizing can, in turn, result in exposure to a new set stressors arising from the moving process (both psychological and financial), and dislocation from the familiar community, neighbourhood and services recognised as important resources for resilience.

Multigenerational Living

In the Living Together study (Liu et al, 2015), an analysis of 2011 Census data (ABS, 2013) revealed that while multigenerational households (defined as those with at least two generations, the younger aged 18 or over) comprised only 15% of Australian households, they represented one fifth (20%) of the Australian population (due to their larger household size) and had remained so since the 1980s (Liu et al, 2015). Most were living in detached dwellings (94% in Brisbane and 83% in Sydney), were homeowners either outright (36% and 31% respectively) or purchasers (42% and 45%), and around one fifth were renting (20% and 22%). Over half (59%) of participating households had at least one person aged 55 or over.

From our survey, the most common reasons given for multigenerational living were financial ones (38% in Sydney and 55% in Brisbane) including the active choice to support adult children at times of difficulty while undertaking higher education, or saving for their own future home, but also the inability of either generation to afford a sustainable housing option. The second most common reason was to provide care or support (19% and 28% respectively), whether for older parents, children or grandchildren, for cultural reasons, or to avoid unaffordable care services. Other less common reasons were adult children not leaving home (18% and 13%) or starting/continuing tertiary education (11% and 13%) and older grandparents moving in (11% and 9%) (Liu et al, 2015).

Our participating multigenerational households experienced a number of challenges. Most common amongst these were problems with privacy or interference (60% in Sydney and 58% in Brisbane) followed by impacts on intra/inter family relationships (19% in both), inequitable contribution to household chores (12% and 18%), space related issues (8% and 11%) and lack of flexibility or compromises (4% and 14%). Other less common challenges included financial arrangements, noise interference, inter-generational agreements or expectations, and the stigma of living at home for the younger generation (Liu et al, 2015).

Some of these stressors were exacerbated by the design of the home, notable those related to privacy, space and noise. Differences in lifestyle and preferences could be compounded by inadequate space, poor definition of generational territories, horizontal or vertical adjacency, and noise separation or insulation. Given the conventional design of Australian suburban detached dwellings, modifications to increase space and improve privacy could be difficult and expensive. Very few had made major modifications to improve person-environment fit, while others, expecting their multigenerational living to be temporary, had only made minor modifications using temporary room dividers or relatively simple garage conversions. Even fewer had adapted to multigenerational living by moving to, or building, a larger dwelling with more independent accommodation (such as a granny flat or similar) and others had contemplated this possibility but been daunted by the cost or ability to find a suitably designed dwelling (Judd et al 2017). While family support has been identified as an important resource for the resilience for either generation in the face of financial or circumstantial stressors, this was rarely supported by housing design that facilitated better definition of intergenerational territory and privacy.

Towards A More Resilient Built Environment for an Ageing Population

It has been established in gerontological literature that housing and the urban environment are important, if indirect, resources for resilience in older age, which is reflected in the residential choices of older Australians ageing in place. In conclusion, we turn to the resilience of housing and the urban environment in supporting Australia's ageing population and how this can be improved.

First, if the predominant housing choice of older Australians is to remain in larger homes in the general community, more needs to be done to ensure that new housing is suitable for ageing in place. Steps toward this in Australia have been slow and minimal. Australian Standards for accessible design have existed since the 1970s, but have not generally been required in private housing. The recent addition of a limited degree of accessibility within apartment buildings under the Disability (Access to Premises) Standards 2010 Act of the Disability Discrimination Act 1992 is welcome but minimal (common area access to one level). Recent attempts to introduce voluntary 'Liveable Housing Guidelines' (Liveable Housing Australia, 2015) have failed to attract wide industry support and meet proposed targets, suggesting that a mandatory approach within the Building Code of Australia is necessary. With over half of all private dwellings being renovated in 10 years, perhaps consideration could also be given to mandating adaptable design in this sector.

Second, it is important to recognise the diversity of the older population in terms of their circumstances and capabilities, which needs to be reflected in the housing options available. Unfortunately, this is not the case, with housing supply polarised around larger detached suburban dwellings and multi-storey inner-city/suburban apartments. Our downsizing interviewees noted a lack of dwellings "smaller, but not too small, single level, step free, with accessible design and a small, manageable garden." This 'missing middle' in the urban housing market has recently been recognised by Planning NSW who have introduced a Draft Medium Density Design Guide (Planning NSW, 2016) to encourage more diversity on the premises of both housing affordability and demographic change. This includes housing types more suitable for multigenerational households, such as accessory dwellings, but still relies heavily on two storey (town house) forms not suitable for ageing in place. Current economic disincentives such as stamp duty taxes and pension eligibility risks along with better information and support services also need to be addressed if moving and downsizing is to be encouraged.

Third, the Australian housing industry's focus has been too much on specialised, age-segregated housing (retirement villages and seniors housing) and needs to recognise that most older people, increasingly baby boomers, largely wish to live in the general community, some in multigenerational households, and thus represents a rapidly growing market sector.

Fourth, there is the need to recognise that successful ageing in place is not just about dwelling design, but also resilient neighbourhood design, facilities and infrastructure that facilitate social participation. Currently there is little coordination between different levels of government in creating age-friendly urban environments, with responsibilities split between national, state and local governments. As our research found, there is also enormous variability in the age-friendliness of neighbourhoods and infrastructure throughout Australia.

Finally, it should be noted that such resilient housing and urban environments are not only important to support successful ageing, but also provide diverse and inclusive options for the wider community.

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Developing Resilience, Independence and Well-being in Older Adults through Interactive Outdoor Spaces

Chelsea Kershaw[1], Joelle Lim[1], Jacqueline McIntosh[1], Jon Cornwall[2], Bruno Marques[1]

[1]School of Architecture, Faculty of Architecture and Design, Victoria University of Wellington, Wellington, New Zealand. email: jacqueline.mcintosh@vuw.ac.nz
[2]Graduate School of Nursing, Midwifery and Health, Faculty of Health, Victoria University of Wellington

Abstract: The morbidity rates in populations of older persons are rising in parallel with increases in life expectancy. Increases in the numbers of older persons, many of whom will be physically dependent, will challenge communities both economically and socially. To compensate for this health loss and the subsequent demands placed on the health care system, there is a growing demand for effective preventative public exercise interventions to enable the ageing population to maintain independence and enjoy a healthier lifestyle. The provision of age-appropriate playground and exercise equipment for older persons has been gaining international popularity and is expected to become increasingly popular among local governments as a direct result of rhetoric relating to the development of age-friendly cities. Using a multidisciplinary lens, this project maps desired rehabilitation outcomes with exercise equipment design and landscape architecture. It seeks to identify both physical and motivational strategies that are most successful in maintaining good health and well-being in old age. Findings suggest that there is demand for open public space interventions that can safely train balance, muscular strength, and cardiovascular fitness. However, there is a lack of health research examining the usefulness and the sustainability of currently available equipment. There is also a necessity to address participation barriers and manage potential adherence issues that prohibit older persons from engaging in beneficial physical activity.

Keywords: resilience, interactive outdoor space, therapeutic landscapes, elderly, playground equipment

Introduction

Older individuals have experienced an unprecedented increase in life expectancy (Mousourakis, 2013). This ageing population is a pivotal demographic shift that will greatly impact the way in which people design and experience landscapes. The global over 65-year-old population is expected to more than double by 2051, whereby the New Zealand elderly cohort is predicted to rise from around 15% in 2016 to 25% by 2051, diminishing the available workforce and expanding the disabled population (Mousourakis, 2013; Statistics New Zealand, 2013; 2000). Furthermore, the mandate for health services will be pushed by chronic diseases, which pointedly contribute to the ever-increasing health loss of people over 60, and particularly those over 85 years of age (Ministry of Health, 2016; World Health Organisation, 2011). Concurrently, these issues are expected to cause a significant fiscal crisis, potentially dwarfing that of the recent economic depression (Kowal, et al.,2014). In this ageing society, rising morbidity rates will become a priority for health professionals and planners, and the development of preventative measures will be imperative in minimising the significant demand on the health care system (Kowal, et al., 2014; Kershaw, et al, 2017).

Countless studies validate the abundant reimbursements of outdoor spaces for elderly people, who perhaps have the most time available to capitalise on these resources (Sugiyamao, et al., 2007; Kolt, et al., 2007; Grant et al., 2007). Benefits not only include increased participation in physical activity, but also the potential for increased social interactions. Natural settings foster stress recovery, decreased antagonism, and a documented reduction in developing neuropsychological illnesses (Sugiyamao, et al., 2007; McCormack, et al., 2014). Therefore, the importance for older persons to experience independence in 'natural' public space is potentially significant.

Traditional outdoor physical activity strategies such as leisure activities in parks, or in exercise groups, offer recreational advantages (Matsouka, et al., 2008). More contemporary strategies for engaging with outdoor exercise are through targeted fitness zones, which provide specialised equipment to facilitate cardiovascular, strength, and balance training (Cohen, et al., 2012; Volkanovski, 2015). Ever-increasing in popularity, these zones are increasingly being adapted for senior use to not only train for increased aerobic and muscular strength but also to improve motor functioning, balance and flexibility. These settings have the potential for improving overall well-being and increasing resilience to frailty (Kershaw, et al., 2017; Volkanovski, 2015). Developing an understanding of the effectiveness of these exercise strategies is essential to inform the development of future outdoor interactive spaces, which are effective at encouraging exercise participation for developing resilience, independence and well-being in older persons.

Method

The research method involved a review of the rehabilitation literature that examines both physical and motivational outdoor exercise strategies most effective in maintaining good health and well-being in older persons. The results of this were then compared against a systematic evaluation of current outdoor exercise equipment to establish the suitability of those designs and to identify appropriate design parameters for the development of future outdoor interactive spaces that are adequately equipped to manage this susceptible ageing community.

Findings

Many systematic reviews were uncovered which outlined the different physiological needs of older persons, for the prevention of age-related morbidity. It was found that globally there was much agreement on the required levels of physical activity for older persons for maintaining health and wellbeing. Studies highlighted the significance of outdoor spaces for the promotion of physical activity in older adults through methods such as recreation in parks, group fitness, interactive exercise equipment or elderly playgrounds. In particular, there was substantial support for developing interactive outdoor spaces for managing the ageing populations.

Suitability of Exercise for Elderly Persons

A large majority of independent unimpaired older persons have the capacity for participating in moderate to high intensity exercise (Brown, et al., 2011). Thus, recommendations for cardiovascular, strength and balance training is relatively comprehensive in order for people over 60 to maintain independence, prevent non-communicable diseases, and build resilience to falls and frailty (World Health Organisation, 2010). The New Zealand Ministry of Health recommends older adults engage in a minimum of 30 minutes of moderate aerobic activity, 5 days per week. This could include brisk walking, cycling, kapa haka (a Maori performing art), kilikiti (a Pacific Island version of cricket) or playing with grandchildren (Ministry of Health, 2013). There are also the options of vigorous aerobic exercise, such as running, tennis, hiking, energetic dancing or martial arts, to a total of 75 minutes per week (Ministry of Health, 2013). Additional resistance training on major muscle groups such as legs, hips, back, abdomen, chest, shoulders and arms should be undertaken at least 2 days per week to receive muscle and bone strength benefits (Hurley, et al., 2000; Seguin, 2003; Ministry of Health, 2013). Sessions of flexibility and balance exercises are also extremely beneficial for elderly persons' to improve mobility and increase resilience to falls and injury. This could include modified tai chi, stretching, yoga, pilates (Ministry of Health, 2013; Chen, et al., 2007; Mason, et al., 2013; Pata et al., 2014). For impaired elderly, the range of ability is still quite varied and recommendations suggest participation as capability allows (Ministry of Health, 2013). Consequently, progressive rehabilitation and preventative strategies for improving independence and well-being would seem essential for outdoor interactive spaces.

Suitability of Interactive Outdoor Spaces

While there is numerous research on the effectiveness and adherence of traditional outdoor exercise strategies (Ishee, 2004; Laurant et al., 2002; McPhate et al., 2013), very little research has been published on the application of modern outdoor fitness equipment for elderly participation (Chow, 2013; Cohen, et al., 2012; Betterncourt, et al., 2012; Cranney, et al., 2016; Mitchell, et al., 2007; Scott et al., 2014). Additionally, studies which test the health implications of outdoor exercise equipment on elderly persons were limited to: a study of balance training in elderly women using public parks, Leiros-Rodriguez, et al., 2014) another study on the physiological effects of outdoor exercise equipment in elderly people, (Kim, et al., 2013) and two studies which assessed the effects of an outdoor recreational exercise program on sedentary seniors (Mitsouka, et al., 2008; 2008b).

Recreation in Parks / Group Outdoor Fitness

Studies showed that group outdoor fitness was very beneficial in providing the social interaction and leisure which helped for exercise adherence (Young, et al., 2016). The adaptable nature of group classes meant that changes could be made to suit preferences and interest to increase uptake. A limitation of this method of exercise is its exclusivity, as it is often targeted towards specific demographics and may be inaccessible to certain cultural groups or people with low esteem (Francis, 2014). Additionally, the reliance on other people for direction or motivation, the lack of equipment and low self-efficacy were deemed to be detrimental to long-term adherence (Grant, 2008). Furthermore, in instances without feedback it is difficult for elderly persons to undertake appropriate levels or types of exercise, or to monitor their progress. A systematic review conducted in 2002 found that common participation barriers for exercise in public green spaces were that; the provided spaces were not appropriately designed for elderly physical activity; environmental factors such as lack of scenery and vegetation resulted in undesirable settings; exercise surfaces were often of poor quality, a lack of equipment limited opportunities for exercise (Francis, 2014; Humpel, et al., 2002). Without adaptation currently existing public parks may not have appropriate or maintained facilities for effective physical activity, reducing enjoyment and safety (Grant, et al., 2007).

Outdoor Exercise Equipment

Research found there is a strong demand for age-friendly exercise equipment within the outdoor public sector, as elderly people have a stronger tendency for participating in exercise in an outdoor environment, if it is well-designed (Kim, et al., 2013). Additionally, there are many economic barriers, which prevent people from engaging with beneficial exercise which must be addressed when designing within public space (Loukaitou-Sideris, et al., 2016). This can be seen in the numerous case studies of free outdoor fitness zones which are increasing in popularity globally and are becoming increasingly implemented in public parks (Chow, 2013; Volkanovski, et al., 2015; Cranney, et al., 2016; Elwell, et al., 2016). These interventions are of specific significance for people of low socio-economic status, whom are more likely to face health problems and may have scarce access to health care and exercise equipment (Elwell, et al., 2016).

Based on an assessment of exercise equipment currently available of the market, it was found that many of the elements do target muscular strength, balance and cardiovascular fitness in older adults (Caldwell, 2010; Martin, et al., 2007). However, the resemblance to indoor gym equipment is uncanny, with only equipment materiality altered to be more durable in outdoor conditions (Caldwell, 2010). Thus, the only key difference between outdoor and indoor equipment is that comfort is often stripped when adapting it for outdoor use (Chow, 2013). Therefore, there is a requirement for better-fit, ergonomic designs to make outdoor gym equipment more comfortable for older persons, while ensuring and outdoor maintenance is still a significant design parameter.

While there is an essential need for the equipment to be designed to effectively target specific muscles and bodily systems, which the equipment seems to do, the existing capabilities of older persons need to be considered for equipment to be utilised for strength maintenance and rehabilitation in a safe manner (Aparicio et al., 2010). This is a main concern for many older persons, who find equipment intimidating and have health and safety concerns such as physical disabilities (Fredriksson, et al., 2011). We suggest there a need for progressive adaptable elements to allow for a diverse range of capabilities as well as systems that provide meaningful feedback.

Adherence rates for the utilisation of outdoor interactive spaces also need to be addressed. One study showed that within 6 months of engaging in physical activity, 50% of participants dropped out before they were exposed to any long-term health benefits (Schutzer, et al., 2004). This is a significant problem as once exercise participation ceases, the health benefits are quickly lost (Schutzer, et al., 2004). Other issues identified include a lack of encouragement, energy and time, or perceptions of incapability due to old age (Kolt et al., 2007; Grant, et al., 2007). In addition, lack of company or interactivity was another common theme (Grant, et al., 2007). This suggests that while the equipment may be appropriate for the required training of balance, muscle strength and cardiovascular fitness, the equipment may be ill-suited for the physical, mental and social disparities within ageing population. Furthermore, the equipment may not inspire the social behaviour and confidence that are deemed essential for adherence. In summary, while it is important to establish stimulating exercise strategies for elderly persons to maintain long-term engagement, there are significant participation barriers, which need to be adequately addressed to successfully engage older persons in physical exercise. We conclude that while there is now a wide range of equipment available on the market, it is not mentally stimulating enough to encourage long-term participation (Lim, et al., 2007) and there may be a need to provide a form of interactivity or feedback system into the outdoor exercise equipment to develop physical activity motivational strategies (Kelders, et al., 2016).

Elderly Playgrounds

One attempt to address needs for increased social interaction and feedback and introduce some enjoyment is the clustering of fitness equipment into playgrounds for the elderly. The design challenges for these senior playgrounds have been to either adapt previous equipment to be more enjoyment and sociable, or to develop an entirely new concept which is enjoyable, yet efficient at training balance, muscular and cardiovascular fitness. Manufacturing companies developing equipment for these outdoor spaces include Kotobuki and GameTime who often modify existing exercise equipment for elderly play such as new interactive bars adapted from lateral pulldowns. Other companies, such as Xccent and Lappset have focussed designs around improving daily functioning and improving balance and proprioception for fall prevention in older adults (Lim, et al., 2007). A Lappset study showed that interactive equipment such as the high horizontal bar was useful for exercising the upper body for flexibility and strength, which could aid individuals in reaching high shelves, putting on shoes, or hanging laundry (Lappset, 2014) Another designed element involved walking on varying surfaces to develop lower body strength and joint flexibility for improving mobility up and down stairs and for moving in and out of a chair (Lappset, 2014). While marketed as play equipment, these elements were perhaps the least interactive pieces in the playground compared with the swing, or tai chi wheel so there may still be a disconnect between physiological needs and the requirement for psychological stimulation.

Recent studies show that currently elderly playgrounds are effective at enticing seniors to engage which is stimulating a cultural shift towards an acceptability for exercise and exercising with equipment among older adults (Cranney, et al., 2016; Scott, et al., 2014; Scott, 2006; Neville, et al., 2013). It appears many hesitant older persons were sufficiently intrigued by the new playgrounds that they let go of the notion that they were either too old to exercise, or their fears of appearing silly (Scott, 2006). Research found that participation in exercises in this form promoted social interaction among elders' as it provided a platform for them to meet for group exercise. Consequently, these interactions allowed increased encouragement towards participation and adherence (Loukaitou-Sideris, et al., 2014). This is particularly beneficial as studies found that female seniors preferred to exercise in groups, as it gave them more motivation, confidence and enjoyment (Chow, 2013; Leiros-Rodriguez et al., 2014). Through this social interaction, important relationships may be developed for overall wellbeing and improved quality of life. Furthermore, a study found that the inclusion of a trainer or supervisor, for introducing elderly to the equipment increased confidence within participating seniors, thereby increasing the efficacy of these therapeutic landscapes (Mitchell, et al., 2007; Scott, et al., 2014; Leiros-Rodriguez et al., 2014).

As senior playgrounds have only recently gained international popularity, there is the risk that the equipment may not be entirely fit-for-purpose despite the increasing inclusion of interactive elements. Furthermore, there are limited studies on the effectiveness of this play equipment for improving balance, muscular strength and cardiovascular fitness, or the long-term usage. In addition, very little research was found regarding the ethnic, cultural, and gender barriers. These knowledge gaps must be addressed in future research to ensure appropriate development of interactive outdoor spaces that are inclusive for all elderly populations

Conclusion

This paper explores the potential of exercise strategies in interactive outdoor landscapes, by integrating cross-disciplinary knowledge to identify appropriate design parameters of these spaces. It argues that the interactive outdoor landscapes can be beneficial to elderly lifestyles for maintaining their independence and well-being. Findings suggest that there is demand for public open space interventions that can safely train balance, muscular strength, and cardiovascular fitness. However, there is a lack of research with respect to both the usefulness and the appropriateness of currently trending senior exercise equipment, which may not be fit for purpose for this older age group. Additionally, while there is promising enthusiasm around contemporary outdoor senior fitness equipment there are still physical activity participation and motivational barriers for the older person. In addressing adherence barriers findings suggests that more interactive and engaging exercise equipment, improved feedback systems and better integration with outdoor landscapes, could promote long-term effectiveness of physical activity for the elderly. Furthermore, to overcome additional participation problems, further research is required on specific ethnic, cultural, gender and age barriers.

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Design to Thrive

Models of care and physical environments of current housing for the elderly: the possibilities of the rental housing for the dependent elderly in New Zealand

Yukiko Kuboshima[1], Jacqueline McIntosh[1], Geoff Thomas[1]

[1]School of Architecture, Faculty of Architecture and Design, Victoria University of Wellington, Wellington, New Zealand. email: jacqueline.mcintosh@vuw.ac.nz

Abstract: There is a scarcity of suitable housing options for the elderly who need assistance to live independently in New Zealand. Currently, there are three main types of housing; retirement villages, public-sector housing (central government and local council), and private-sector rental housing for the elderly. However, the rapid growth of the ageing population means that demand far outweighs supply. In particular, there is an increasing need for rental housing. The objectives of this study are; to identify the features of each type of housing, and to explore the models of rental housing for the elderly who need assistance. Data has been collected through archival research and a questionnaire survey for housing operators on the models of care and the physical environments of these three types of housing in the Wellington Region. Rental housing is most typically provided by the public and private sectors, however, they are less likely to provide high levels of services for the elderly, with some exceptions in the private-sector housing. The government policy objectives associated with 'ageing in place' are unlikely to be achieved if this imbalance of suitable housing supply for dependent older people and the demands for such housing which allows them to remain independent cannot be addressed.

Keywords: Housing for the elderly, dependent elderly, models of care, physical environment, rental housing

Introduction

Globally, the ageing population is projected to increase rapidly. As people age, they experience greater difficulty performing everyday tasks such as those involved with maintaining their own home. In addition, the elderly typically have a higher prevalence of psychological concerns such as insecurity, loneliness and isolation (Davey et al., 2004, Jaye et al., 2015). At some point, typically in their 70s or later, these experiences induce them to seek a more suitable dwelling (Statistics New Zealand, 2002). Unfortunately in New Zealand, the supply of suitable housing is in short supply and the government policy has been to encourage ageing in place. To successfully achieve ageing in place, which puts the focus on avoiding entering institutional residential care (Davey, 2006a, Ministry of Social Development, 2001), the housing for the elderly needs to provide an adequate environment for the provision of support and care.

When older people need more assistance, some consider moving closer to their children; but most do not want to live with family in order to avoid being a burden (Davey, 2006a). However, there is a scarcity of suitable independent housing options for the elderly who need assistance to live on their own in New Zealand (Davey, 2006b). Currently, there are three main types of housing which provide some level of care and assistance; retirement villages, public-sector housing (central government housing and local council housing), and private-sector rental housing, which includes community providers and various other groups who provide for older people. While often retirement villages require the execution of 'Occupation Right Agreements' which state that a resident who cannot live independently may lose their right of residence, many retirement villages in New Zealand provide a continuum of care by physically attaching residential care facilities to independent and/or assisted living units. Retirement villages offer company and security, reduce concerns about home maintenance and are viable options for current homeowners and the relatively well-off. However, they are not viable options for those without substantive savings because the majority require some form of capital contribution, such as the purchase of a Licence to Occupy (Greenbrook, 2005).

Local authorities provide affordable housing and some of them provide social support for older people to live independently (Davey et al., 2004). Central government (Housing New Zealand) also provides affordable housing but does not with support especially for older people to live independently. Of the private-sector rental agencies, religious and charitable groups, which have been the providers of choice for the government, have been withdrawing from the older persons' residential accommodation sector. This is largely due to their inability to afford to upgrade facilities to make them suitable (Povey and Harris, 2006). Recent government initiatives are seeking to address this situation, encouraging community housing sectors to grow (New Zealand Government, 2015).

The number of units in retirement villages in New Zealand was 32,854 in 2014, with the penetration rate of 12% among those aged 75 and over (JLL, 2015). The demand for retirement villages has been projected at an increase of more than 50,000 units between 2014 and 2038 with the scenario of the same penetration rate, which equates more than 1.5-time increase (JLL, 2015). Shortages are currently reported in private-sector rental housing for the elderly in Auckland (Seniorline, 2016).

New Zealand is a bicultural country, predominantly populated by people of European descent. Of older people, non-European groups are more likely to be renting than those of European descent (Davey et al., 2004). This has implications for rental housing as the proportion of non-European people is expected to grow significantly (Statistics New Zealand, 2013). In addition, the levels of homeownership among people in mid-life are falling (Davey et al., 2004). The combination of these two factors will increase the demand for rental housing in the future. The retirement villages, which mainly accommodate homeowners, provide high levels of care as part of the continuum of care; however, the possibility of rental housing accommodating the highly dependent elderly is unknown.

Objectives and methods

The objectives of this research are to identify the features of each type of supported housing in terms of their models of care and their physical environments to better understand the options available for the elderly who need assistance in rental housing. While information on retirement villages is publically available, there is a scarcity of information on the other two forms of housing, especially private sector rental housing for the elderly. The focus of this study is to obtain equivalent information for all three types of housing, so as to enable a clearer, more direct comparison and better understand the rental options for the elderly.

Data was collected through archival research followed by a questionnaire survey for housing operators of retirement villages, public-sector housing, and private-sector rental housing for the elderly in the Wellington Region in New Zealand. First, information on the housing was obtained through the websites such as housing operators' homepages and/or the websites that provide comprehensive information on services for the elderly (Eldernet

Ltd, 2017). Next, data on the models of care and the physical environments of the housing was collected from housing operators. The sample was limited to housing sites with eight units or more. Data was collected using online questionnaire software or questionnaire forms attached to emails, and complemented by additional emails and/or interviews.

Physical environments and models of care

To gain an initial basis for comparison, the total number of units per site were compared by housing type in the Wellington region (Table 1). The average number of units was the largest for retirement villages, which included a wide range in the size of complexes, from 20 units and less to over 200 units. The size of public sector housing varies, and the majority were complexes of 20 units or less. The size of complex was the smallest for private-sector rental housing, with over 80% of the sites containing 20 units or less (Table 2).

Table 1. Total number of units and the size of the housing complexes

Type of Housing	Unit number (percentage)
Retirement villages	2862 units*
Public-sector housing for the elderly	2622 units**
Private-sector rental housing for the elderly	276 units

*The total unit number of retirement villages doesn't include those of two villages which are unknown.
**Of the public-sector housing only the number of units which are occupied by people 65 years are included in this table.

Table 2. Number of units per housing site (among the housing sites with 8 units and more)

Type of Housing	Average number of units per site	Number of units per site							
		8-20	21-40	41-60	61-80	81-100	101-200	201-300	Unknown
Retirement villages	95	25%	9%	13%	0%	9%	19%	19%	6%
Public-sector housing (excluding HNZ)	40	54%	22%	3%	5%	3%	10%	3%	0%
Private-sector rental housing for the elderly	15	82%	12%	6%	0%	0%	0%	0%	0%

The data on communal spaces and the services provided for residents in three types of housing were collected by questionnaire survey. For the analysis, retirement villages were divided into two types; independent living units and assisted living units (Figure 1, 2). Retirement villages provide a wide range of communal facilities such as lounge and community rooms; dining rooms and restaurants. All assisted living units in the retirement villages were attached by the lounge/community room and the dining room. In contrast, most public-sector housing sites had either no communal space or only the lounge/community room for shared use. The communal spaces provided by the private-sector rental housing providers were also relatively small and the spaces varied in type (Figure 1).

With respect to services for residents, retirement villages provide the widest range of services. For example; all villages that participated in the survey provided emergency on-call 24 hours a day, most arranged to visit residents regularly and organised activities and outings the costs for which were included as part of the 'Licence to Occupy', or in the 'Weekly Fees'. Assistance with transportation, meals, laundry and other assistance with household tasks were provided either inclusively or with extra cost. The services for residents in assisted living units are greater than for those in independent living units. Public-sector housing provides emergency-on-call service and social support such as regular staff visits, organised activities and outings at over half of the sites. Most private-sector rental housing provides regular staff visits, which may be accompanied by other services but services vary by the site.

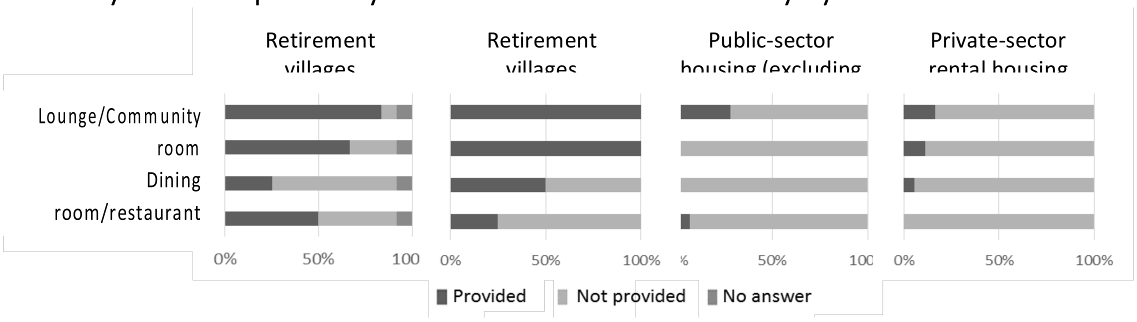

Figure 1. Communal space for residents

Figure 2. Services provided for residents

Levels of services

To compare the levels of service, the services provided for residents were given scores as; 'provided without extra cost'=2, 'provided with extra cost'=1, 'not provided'=0. Then the housing sites were classified by the total scores for 10 kinds of services; 0-3: low levels of services, 4-9: medium levels of service and 10 and over: high levels of services. The retirement villages were divided into independent living units and assisted living units. The table 3 shows the number and the proportion of housing sites by the housing type and the levels of services. The residents in most independent living units, and all of those in assisted living units in retirement villages are provided with high levels of services. The public sector provides either low or medium levels of services. The levels of services provided by private-sector rental housing are relatively low overall but have a wide range.

Table 3. Levels of services by the housing type

Housing sites		Low levels of services	Medium levels of services	High levels of services
Retirement villages	Independent living	0%	20%	80%
	Assisted living	0%	0%	100%
Public-sector housing (except for HNZ)		35%	65%	0%
Private-sector rental housing for the elderly		78%	17%	6%

Characteristics of each type of housing

Retirement villages

Of three housing types surveyed, the overall size of the housing complex was the largest for retirement villages. They provide the widest range of communal facilities, services for security, facilitating activities and assisting with household tasks than other two types of housing. 'Independent living units' and 'Assisted-living units' are the well-known classifications of the units by the level of care provided in retirement villages.

a. Independent living model
Independent living units are self-contained villas, flats, townhouses and apartments that are physically separated from residential care facilities, if they are provided on the site. Residents can make use of internal and/or external service and care providers for support with household tasks and personal care, as well as other services. The inclusion of services are variable by complex, some provide these services for no additional charge and some charge by use.

b. Assisted living model
Assisted living units are designed to bridge between independent living units and full residential care in the continuum of care. They are often called 'serviced apartments.' The units are all self-contained apartments with the lounge and the dining spaces. They are often connected internally to the residential care facilities, so that flexible and efficient services and care can be provided to residents. Services for items such as social activities, household tasks and meals are typically financially combined with the housing unit in this type of housing.

Public-sector housing

There is a wide range in terms of unit size in the public sector, but over half of the housing sites were small containing 20 units or less. The units were self-contained villas, flats and apartments with limited communal space. Some housing complexes with relatively large numbers of units had communal spaces such as community rooms. The services for the residents varied, but residents who need assistance in household tasks and/or personal care receive services from external service/care providers, which include those allied with District Health Boards. The types of the housing are classified by the levels of services as below;

c. Housing with low levels of services
This type has no communal space. The only service provided is regular staff visits.

d. Housing with medium levels of services
The residents of this type of housing are provided with organised activities, outings and/or transportation as well as regular staff visits. Some of the complexes had one or more communal spaces, which were used for organised activities. Residents in complexes with no communal spaces were encouraged to use external facilities, such as community spaces in other complexes; community halls; the church, or public libraries for social activities.

Private-sector rental housing for the elderly

Both the total number of units and the size of the housing complex is considerably smaller in private-sector rental housing. Some rental housing complexes are located adjacent to residential care facilities. The number of communal spaces for the use of residents in rental housing, which may include those in residential care facilities, are relatively few, and might include dining/restaurant spaces, lounge or community rooms, or a shared kitchen. Residents in most sites receive regular staff visits. The private-sector rental housing has a variety of models in terms of the levels of services provided and the unit types which can be classified into four types as shown below.

e. Housing with self-contained units and low levels of services

The majority of private-sector rental housing sites are of this type, which is similar to the housing with low levels of services in public-sector housing. The units are self-contained villas and flats and most sites have no communal space for residents. In most sites, the only service provided is regular staff visits. This type of housing includes some units which were formerly owned by the public-sector but were sold off to private-sector rental agencies.

f. Housing with self-contained units and medium levels of services

In most sites of this housing type, residents are provided with organised activities as well as regular staff visits. Some sites which are located adjacent to residential care facilities provide organised activities for the residents using the spaces in the adjacent residential care facilities but provide no dedicated communal space.

g. Housing with semi-self-contained units with medium levels of services

The combination of services provided in this type of housing are all inclusive; regular staff visits, meals and other services which are provided by a housekeeper without extra cost (included in the rent). Each unit is semi-self-contained with a kitchenette containing a sink and space for a fridge. The residents share spaces such as a full kitchen and dining room as well as the lounge. To be eligible for this type of housing, residents must be independent, but they can obtain external assistance for additional household tasks and/or personal care.

h. Housing with semi-self-contained units with high levels of services

This housing type is similar to assisted living units in retirement villages in terms of the high levels of service and care provided and the indoor connection to the residential care facility; however, the units are semi-self-contained with a kitchenette containing a sink and a fridge, rather than the full kitchen provided in the assisted living units in retirement villages. These rental units contain a lounge and a dining area, and the residents are provided with a wide range of services such as; regular staff visits, organised activities and outings; transportation, meals, as well as assistance in household tasks and personal care with extra cost.

Discussion

Ageing in place, which is preferred by the elderly themselves as well as by the New Zealand government, implies that 'older people remain in the community, rather than moving into residential care' (Davey et al., 2004). However, the realisation of ageing in place cannot be achieved without suitable housing and the provision of service and care which supports the elderly person's independent life. Retirement villages, which are the most viable option for those with sufficient capital (often former home owners), can accommodate high-dependency elderly. However, for those who require rental housing, which is provided mainly by the public and private rental sectors, the options for those elderly who need high levels of care are scarce. To cater to this ever-growing sector of the elderly population, strategies to provide the services they need with the limited resources and space are urgently required.

The combination of service provision with housing creates difficulty for all housing providers; however, some are more challenged than others. With respect to the more expensive end of the housing spectrum, a recent study reported that the residents in assisted living units in retirement villages reported experiencing a lower quality of life, because of size and inadequate spaces as well as the loss of privacy with regard to personal care (Hayward, 2012). At the other end of the housing spectrum, the experience of rental housing shared all of the same issues, in addition to the added challenges associated with limited resources.

Housing available for those seeking to rent rather than own is problematic. The public and private-sector rental housing providers are limited in what they can afford with the limited resources made available from low income rentals. Their numbers are limited simply due to availability. Both public and private-sector rental housing providers operate with smaller numbers of units which makes provision of additional services uneconomic for in-house service. Both typically operate with an older housing stock which has not been designed for those elderly who have mobility issues or are not fully independent. Both operate with limited resources and serve those in most need, both in terms of health and mobility, but also in terms of income.

Strategies which could improve the quality of space for the high dependency older population include, more flexible design of communal spaces; organising external transportation options with housing; modified meal service options for use in a minimal kitchen space; and increased efficiency of adjacent facilities. More specifically:

a. In public and private-sector rental housing with medium levels of care, the communal space, often called the 'community room' could be easily adapted for multiple-purposes for various organised activities and other services.

b. In public-sector rental housing with medium levels of care, activities could be organised using other public facilities in the community, such as public transportation services for those who have difficulties in mobility.

c. The private-sector rental housing includes semi-self-contained units, which have a kitchenette, not a full kitchen. This is provided on the premise that the main meals will be provided communally. With the increased availability of commercially-available prepared meals, a well-designed kitchenette might be suitable for some who cannot or does not wish to prepare complete meals or does not want to eat communally. This could reduce the cost of providing a full kitchen.

d. Physically locating the housing units adjacent to residential care facility is a strategy for the provision of high levels of care, as seen in the assisted living units in retirement villages. Some private-sector rental housing provide high levels of care (and have specialised residential care units), however those that provide medium levels of care have no communal spaces for rental tenants. By attaching to a main residential care unit services such as organised activities and meals could be provided using the spaces and the staff of the residential care facilities.

Combining the service and care should also be accompanied by the appropriate physical environments and vice versa. Even new housing designs are rarely designed with an understanding of the special needs of the highly dependent elderly. For example; the space for the service staff should be considered in all such housing; rarely do showers have sufficient room for two and in the designing a communal room, it should be flexible enough to accommodate multiple uses. Similarly, semi-self-contained units should not be without the consideration of meal service. Further exploration is necessary for models of housing which provide greater quality of life along with accommodating higher levels of services and care for dependent people in order to live independently. This should be of equal consideration in the setting for rental housing as well as that for the more exclusive retirement villages.

With limited resources, comes the need for expanded ways of thinking and greater creativity. Questions of how rental housing can provide services and care for its residents through careful placement of adjacent services; or how tenants can work more effectively with the landlords in service provision are rarely addressed. Many rental housing tenants have access to external services for assistance in household tasks and personal care. Partnerships between housing providers and service/care providers could provide a more supportive service system for the elderly to live independently. It has been reported that there are some public sector housing providers that facilitate high levels of care for the elderly through the partnerships between housing and/or services providers, such as those between local authorities and District Health Boards; private-sector rental housing providers or local community trusts (Davey et al., 2004, Reid, 2008). However, this study could identify no such example in the public-sector housing in the Wellington Region. Increasingly providers of social housing for the elderly are expected to exhibit greater innovation and develop better combinations of housing and services to meet people's needs (New Zealand Government, 2015). This is indeed necessary but there also needs for greater consideration of those aspects that contribute to an improved quality of life for residents in the design of their individual spaces.

Conclusion

Agencies that provide both housing and care are most commonly found in retirement villages where home ownership is essential. These facilities can offer high levels of service due to the high number of units, the security of income and housing tenure.

In retirement villages, the elderly who need assistance are aided to live independently with a wide range of services and care; however, this option is mainly for homeowners. The demand for rental housing is projected to increase. Rental housing is provided both by the public and private sectors; however, they are less likely to provide high levels of services for the elderly, with some exceptions in the private-sector rental housing.

The objectives associated with 'ageing in place' are unlikely to be achieved if this imbalance of suitable housing supply for dependent older people and demands for housing which allows them to remain independent cannot be addressed. The research finds some strategies to provide the services with the limited resources and space; however, more solutions are required to combine high levels of services/care with housing. There are possibilities for providing innovative models of care, potentially facilitated by social-housing providers or through partnerships between public sector housing and service providers. Further research is needed for the specific housing models that could provide greater quality of life along with higher levels of services to accommodate the dependent elderly, in rental housing as well as other types of housing.

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An Analysis Tool to match Home environmental Interventions to the specific Needs of People with Dementia

Christine Naumann[1], Ulrike Höhmann[2] and Uta Pottgiesser[1]

[1] Detmold School of Architecture and Interior Architecture, Ostwestfalen-Lippe University of Applied Sciences, Detmold, Germany, christine.naumann@hs-owl.de;
[2] Witten/Herdecke University, Department of Nursing Science, Witten, Germany

Abstract: Background: The number of people with dementia will increase tremendously within the next decades. Aim: The aim of the project was to develop an analysis tool that matches home environmental interventions to dementia-related needs. Methods: A systematic literature review was conducted to evaluate possible home environmental interventions for community-dwelling people. The analysis tool was developed taking into account current German health care regulations and dementia-specific needs that might be influenced by interventions in the built environment, in particular the domestic environment. Results: The analysis tool is an aid to help with better decision making when planning home improvement measures for people with dementia and shows the spectrum of possible interventions to meet individual needs. Conclusion: The main precondition for the use of this analysis tool is the need to assess the specific situation and the individual abilities of people with dementia. The complexity of the domestic environment can only be illustrated if personal and environmental requirements for the respective intervention are determined. The detailing of these factors will follow in a further study.

Keywords: dementia, home environmental modification, fit, dementia-related needs, instrument/analysis tool

Introduction

Advances in medicine, a decline in birth rates and increased longevity all contribute towards demographic changes and an ageing population in Germany. According to current population projections by the German Federal Statistical Office the percentage of the population aged 65 and above will increase from 21% (2013) to 28% (2030) and 33% (2060). In particular, the number of people aged over 80 will go up from the current 5% to 8% (2030) and about 13% (2060) (Pötzsch et al., 2015).

With increasing age, the probability of a progression of age-associated diseases such as dementia rises, too. Dementia is a syndrome associated with progressive memory loss and impaired cognitive and physical ability. The progression and reduction of abilities vary greatly from person to person. After 60, the probability of developing dementia doubles every 5 – 6 years (Ziegler et al., 2009). According to projections by the German Alzheimer Society the number of people with dementia will increase from the current 1.5 million up to 3 million in the year 2050 (Bickel, 2014).

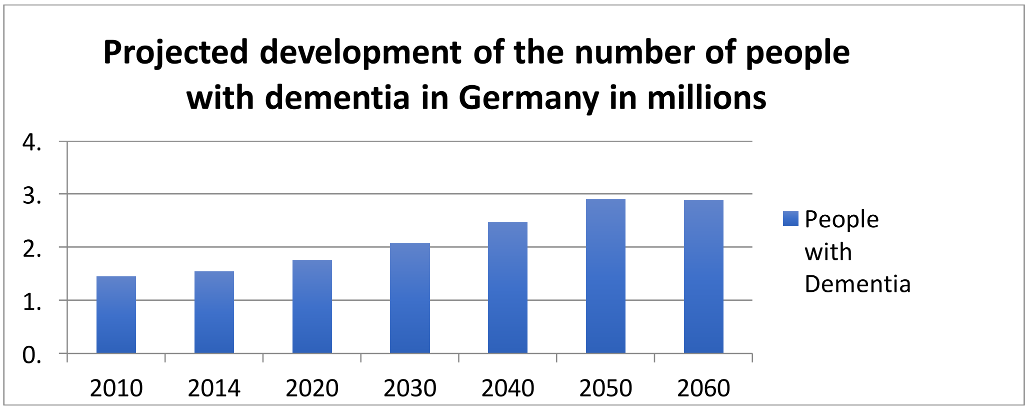

Fig. 1 Dementia in the age group 65 and older in Germany, 2010 – 2060 (German Alzheimer Society, 2014)

The majority of people with dementia live in in their home environment. Restrictions that may occur due to dementia – such as a decreasing ability to make logical decisions or impaired perception and orientation – can jeopardize the ability to lead an independent life. With progressing dementia, the dependence on personal support increases and with lower ability to cope with everyday challenges, caring relatives often feel burdened by more care dependency and incidences of challenging behaviors. These reasons are often reported when care in the familiar environment can no longer be maintained (Schäufele et al., 2005).

Measures to improve the domestic environment for people with dementia

Home adaptions include a number of building- and structural measures in the familiar environment, usually for people requiring care or for disabled people. The guidelines for living space interventions eligible for aid are defined in the German Social Code (SGB XI) which states that nursing care funds can subsidize improvement measures in the home if these substantially facilitate care or allow a person to mainly live independently again (sect. 40 SGB XI, 2017).

Due to the loss of competences associated with dementia, the demands on the environment go up as the symptoms progress and it gets continuously harder for the afflicted to adjust to their surroundings. Studies with people with dementia have shown that adjustments to the built environment can compensate for individual losses by making the right adjustments for the needs of people with dementia (van Hoof et al., 2010).

The adjustments to the environment should compensate for building defects or restrictions on the one hand (Soilemezi et al., 2017), but also make up for the individual restrictions of the residents and thereby improve the home situation in view of the special requirements caused by specific physical and cognitive impairments (BMFSFJ, 2002). The corrections to defects in the homes are made to allow people with dementia to lead a safe and independent life (Struckmeyer et al., 2016), to make life easier for those providing care and to allow them to remain longer and better in the own home. Achieving these objectives means interventions that are directed at the individual needs of people with dementia (van der Roest et al., 2007).

Development and objective of an analysis tool

There are a great number of different improvement measures for homes but most focus on the spatial problems rather than on the needs of the persons concerned and least on the special needs related to dementia. The lack of linking interventions with the requirements of the afflicted persons makes it difficult to assess if the measure is appropriate or not. Against this backdrop the following questions directed the development of the analysis tool:

a. Which dementia-specific needs can be met by special improvements to the home?
b. How can a building intervention be matched to individual problems?

The analysis tool systematically links dementia-specific problem areas with structural interventions that are as much as possible evidence-based. Residential consulting offices, which can be found in many German communities, are envisaged as the users of the tool as they can implement the tool in the course of their advising activities; they can point out or recommend possible building adjustments. It is also conceivable that the Health Insurance Medical Service (MDK) uses the tool in the course of assessing a person's nursing care needs.

Background on the legal and domestic situation

The starting point for the development of the analysis tool is the reorientation of the term *"in need of care"*. In January 2017, the Second Nursing Care Act [Pflegestärkungsgesetz] came into force. With the passing of this law, the understanding of what constitutes *"requiring nursing care"* changed in as much that now for the assessment of the degree of required nursing care no longer the amount of time needed for the support due to physical impairment was considered but instead the ability to lead an independent everyday life is reviewed. This competence-based view is of particular relevance for people with dementia since they might often still be physically able to perform certain tasks but are hindered due to cognitive and motivational restrictions to cope independently with complex situations of daily life. This new approach allows to assess the individual needs of a person and to gain a holistic view of a person in everyday life.

Most older people prefer to stay as long as possible independently in their familial environment even if there are impairments. Moreover, it is the national and international objective of policy discourse in this field to rather provide ambulatory than stationary care. However, 95% of existing homes of elderly people lack appropriate facilities for nursing care needs (BMFSFJ & BMGSS, 2005). This assessment is further supported by regional surveys, which show that 26% of owners and 46% of renters mention the need of improvements in their home environment (Balderhaar et al., 2006). For people with dementia it is difficult to compensate for inadequate facilities due to their cognitive and physical restrictions. Therefore they are especially dependent on a suitable built environment, which is appropriate to their individual needs.

Lawton and Nahemow established the relationship between the level of individual competence and the environment in 1973 in their "competence-press-framework". This model describes an individual's ability to cope with the environment as depending on the individuals' degree of competence and the demands of the physical and social environment (Lawton et al., 1973). When the environment exerts significant pressure then the individual is forced to adapt. Failure here leads to discomfort and unease. In particular, in old age and with impairments due to chronical illnesses such as dementia, the dependence increases on an environment that is suitable the individual competences in particular regarding the physical, social and infrastructural features of the environment (Gitlin et al., 2003). Thus it is necessary to adjust the environmental aspects to the (remaining) abilities of the individual in the best possible way (Schneekloth et al., 2005).

Methodological assessment of areas of life, dementia-specific needs and home environmental interventions

In the eleventh German Social Code (SGB XI) the following six criteria are considered authoritative for the presence of health-related impairments (i.e. in need of nursing care):

mobility, cognitive and communicative skills, behavioral and psychological problems, self-sufficiency, coping with and dealing independently with illness- and therapy-related requirements and burdens, structuring every-day life and maintaining social contacts (*§ 14 SGB XI*, 2017). In addition, the assessment should also include the abilities concerning activities outside the home and housekeeping, to enable planning of care and services (*§ 18 SGB XI*, 2017). For the assessment of the extent of care required, the newly defined German assessment (NBA) includes these areas and defines individual modules as illustrated below:

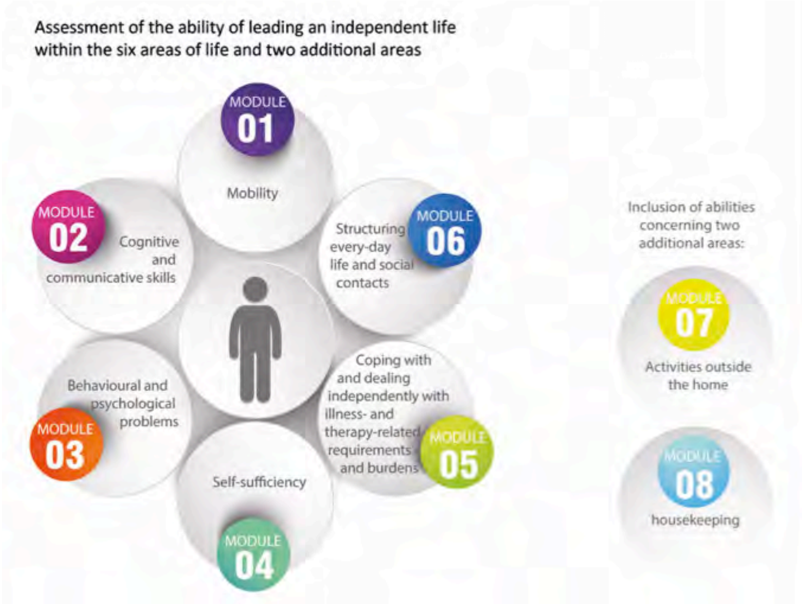

Fig. 2 The six areas of life and two additional areas for the determination of independence. Own diagram based on (NBA, 2015)

In a systematic review of literature interventions were identified which would support people with dementia by independently carrying out the activities of daily living in their domestic environment. The analysis tool included 84 – mainly structural and technical interventions – to support an independent, self-sufficient life of people with dementia.

Typically, the needs of people with dementia differ considerably in scope (Riesner, 2010). Many investigations on the appropriateness and fairness of interventions focus on the care-providing relatives. Only rarely the needs of people with dementia are focused in the context of interventions to improve their home environment. In order to plan and implement interventions with a view on maintaining and supporting resources, need-based and justice measures are of major relevance (van Hoof et al., 2010).

People with dementia often do not only suffer from restricted mobility and physical restriction but they also show signs of cognitive impairment such as problems of perception and orientation. To categorize situations and conditions that trigger the need for support, we used the *"signs and symptoms"* theory coined by MacBryde and Blacklow (1970) for the analysis tool. Signs are objective, physical manifestations and can as such be measured and observed. Symptoms, however, are subjective experiences (such as pain or hunger) and can only be experienced by the person concerned (Cacioppo et al., 1989).

Vague descriptions of symptoms or the limited ability of expression by those concerned can lead to wrong interpretations of needs. There is also the fact that self- and outside assessments by people with dementia and their relatives often differ in regard to the remaining abilities and self-sufficiency (Riesner, 2010). In spite of the challenges of detecting and interpreting symptoms, as mentioned above, the analysis tool integrates the experience of symptoms of the people with dementia and allows a better understanding of the individual situation so that interventions can be targeted directly to the individual needs of the person and the respective stage of dementia (Pynoos et al., n.d.). Fig. 3 shows the categories of typical signs and symptoms of dementia that the analysis tool addresses, on a higher level. The systematic assignment to the dementia-specific needs was made by taking into account the objective of an intervention and the potential effect.

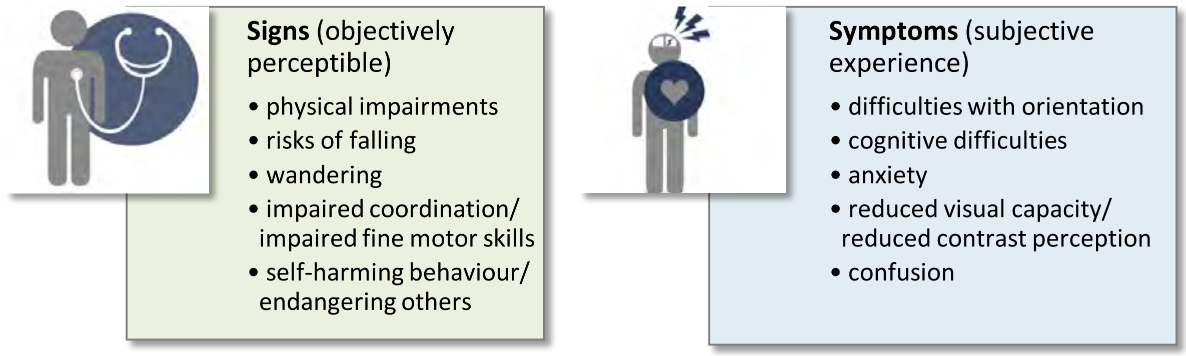

Fig. 3 Relevant signs and symptoms of people with dementia calling for structural interventions

Results and structure of the analysis tool

Therefore the analysis tool is organized hierarchically (Fig. 4). The top level is made up of six **target categories**, according to the six previously identified areas of life and NBA-modules (1,2,3,4,6,8). On the second level, those **items** from the sub-categories of the NBA-module are collected which are relevant for structural interventions (e.g. movement inside the home). Below, on the third level are the **needs** arising from the signs and symptoms of dementia which are linked, on the fourth level, with **measures to improve the domestic environment.** In order to give consideration to the contextual conditions, the interventions are linked to the **individual and environmental resources**. On the lowest level of abstraction there are tables which assign all the interventions included to the respective needs and categories (see Fig. 5).

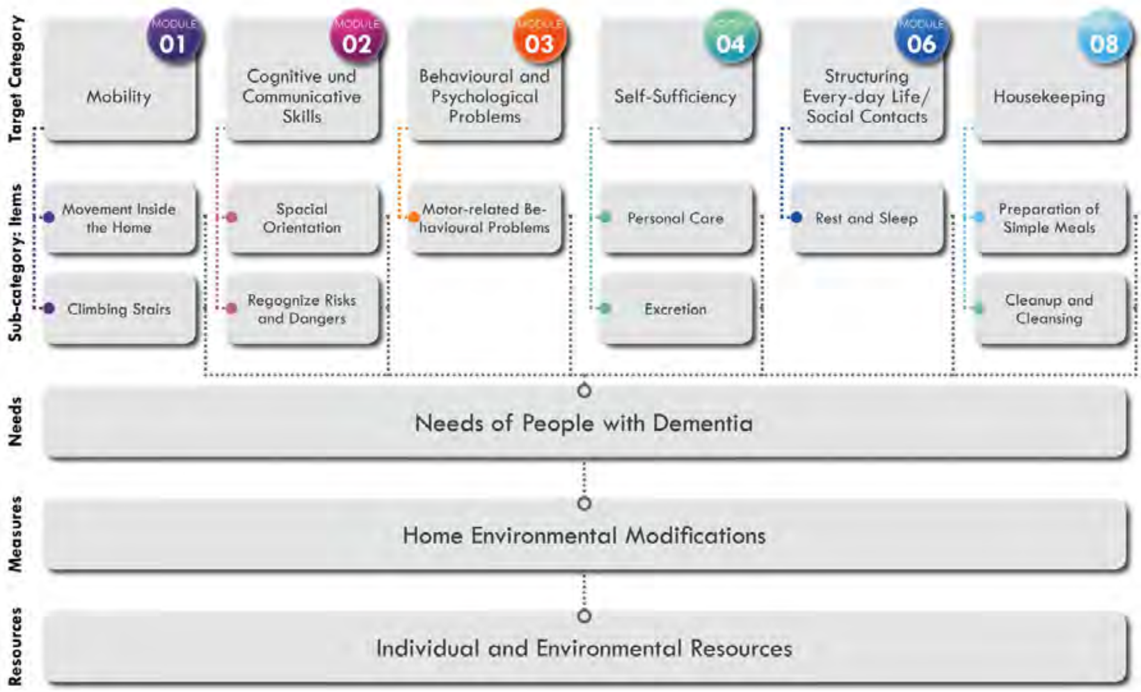

Fig. 4 Base structure of the analysis tool for the assessment of the suitability of measures to improve the domestic environment.

Each intervention for the improvement of the domestic environment aims to meet one – or possible several – specific needs and issues. Therefore, explanatory notes have been prepared for all home improvement interventions that are included. The following figure shows an example of the structure of these overviews. For each **sub-category** of the analysis tool, the specific **needs** of people with dementia, possible **measures** to meet the specific needs resulting from the issue and relevant **explanations** are included.

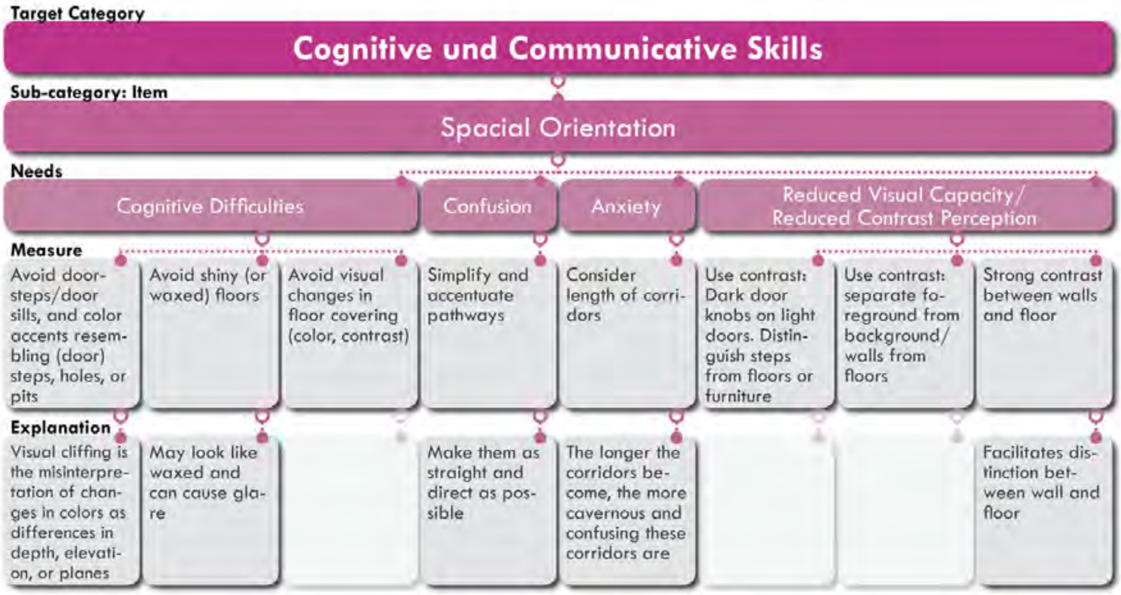

Fig. 5 Home improvement measures to help with spatial orientation

Discussion

The analysis tool is an aid to help with better decision making when planning home environmental interventions for people with dementia and shows the spectrum of opportunities to meet individual needs. Together with the consideration of personal and the environmental circumstances the tool can serve as a decision-making guideline for user-centred needs-based justice and appropriateness of building interventions.

The selection of building interventions is made by matching needs with interventions. The main precondition for the use of this analysis tool is to assess the specific situation and the individual abilities of people with dementia. The determination of individual needs – including both self-assessment and external assessment – will have to be made in future, too, by those concerned, people with dementia, their relatives and professionals. For people with dementia it is difficult to precisely communicate symptoms so that they are constantly on the risk of misinterpretation (Cacioppo et al., 1989). As a result interpretative skills are more important in the determination of the needs of people with dementia than those of people without cognitive and communicative impairments (Riesner, 2010). It is therefore a central condition that those interpretative skills are systematically acquired for the successful application of the tools and they will have to be further developed in future.

Due to the various influences that domestic interventions are subject to, it is difficult to narrow down cause-and-effect relationships, a problem that still exists when the analysis tool is applied. Whatever effects that occur after a home adjustment, cannot be attributed solely to the interventions. There is also the individual disease progression or social changes due to the interventions that can have an influence on the results. The analysis tool does, however, offer a frame for comparison of the effects of interventions in the home environment and a generalization of results might be possible.

Outlook

The complexity of the domestic environment can only be illustrated if personal and environmental requirements for the respective intervention are determined. By adding the environmental resources, the various influencing factors of the built environment can be narrowed down and examined. Linking the measures with the relevant necessary personal requirements is of relevance in terms of improving needs-based justice.

Moreover, the targeted observation of the correlation of dementia-specific needs and requirements for possible interventions allows an exact assessment of potential effects of home environmental interventions on the independence of people with dementia. In a further study the detailing of these requirements will follow.

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Smart environment for the self-sufficient elder users

Gabriella Peretti[1], Francesca Thiebat[1] and Grazia Cocina[1]

[1] Dipartimento di Architettura e Design, Politecnico di Torino, Turin, Italy. Corrispondence email francesca.thiebat@polito.it;

Abstract: In an increasingly demographic and technological transition that is set to radically transform lifestyles and the way living environments are structured, it is necessary that all actors work together and interact with each other, migrating from the concept of a single person to the concept of community. Our proposal, intended to make people's elderly lives easier, aims to bridge the gap between self-sufficient older adults, that do not need constant medical help, and those that need continuous support. Through appropriate technology use, the project aims to integrate and manage the information related to the user, his environment and his health devices. A kind of invisible "smart care network", supported by ICT, unites the places of their everyday lives enabling independent elders to simplify their way of life and avoid being a burden to their relatives. The technological care network must cover three different environments used by the elderly: home, community and the city. The main goal of the research proposed is to redefine the home environment by designing it on the basis of lifestyles habits, the degree of autonomy of the individual and personal needs. The home is connected both to the neighbourhood and to the city providing a link with a community of other users with similar problems and needs, with health and social care infrastructures, local medical clinical centres, recreational activities and various other services.

Keywords: Care network, self-sufficient elderly, smart house, smart city, senior living

Introduction

The ageing population is one of the most important social and economic phenomena both at a national, European and worldwide level. The latest statistical estimations reveal that the population over 60 will represent 1/5 of the world population in 2050, against the current ninth. In Europe, the demographic old-age dependency ratio (people aged 65 or above, compared to those aged 15-64) is estimated to increase from 27.8% to 50.1% in the EU in 2060 (European Commission, 2015).

The ageing phenomenon, regarding the general improvement of the health and independence of older people, brings out the specific requirements, which are different from those of the young and working population. The older adults at this stage of their life have to adapt to living alone in a process of transition that can be painful for those who were used to living with their family or other people.

It is necessary, however, to distinguish between two types of ageing people, those self-sufficient, for whom it is important to provide for integration policies at various levels (city, home, neighbourhood) and those not self-sufficient for whom continuous assistance from caregivers is required. In this paper, we will consider the needs of the self-sufficient elders falling within the state of "active ageing", defined by the World Health Organization "*a process to optimize opportunities related to health, participation and security in order to* *improve the quality of life of older people*" (WHO, 2002). With this intention, WHO has outlined a strategy with the aim of creating and strengthening the conditions for an "active ageing", which is based on three fundamental pillars: Health, Participation and Security. The goal is to foster the transition from policies, based on the needs of older people considered as passive subjects, to policies that recognize every person his right and responsibility to take an active role and participate in community life in every stage of life, including old age. This strategy requires major changes in health, social and environmental systems, in order to improve their effectiveness and efficiency.

The proposal presented in this paper, therefore, is to provide "smart care networks" that simplify and improve the lives of this category of users starting from the redefinition of the home environment and connecting it with the neighbourhood and the rest of the city through the use of ICT technologies.

State of the art: environment for self-sufficient elders

In order to respond to the older people’s needs in a more extensive manner and to improve their autonomy and quality of life, it is increasingly important to find solutions through both “passive and active technologies” (Zallio and Casiddu, 2016). The “passive technologies” collect all the architectural characteristics that an environment must have, to meet the needs of a constantly growing population; the “actives” refer to the technological devices that can help the ageing population to live a safer and more connected life.

The following are examples for both cases: the most common housing typologies currently in use for the self-sufficient elderly and some international examples of smart technologies, tested in pilot projects, able to connect the house with the city.

Current housing typologies for the self-sufficient elderly

The residential options for self-sufficient people are currently the following:

- Collective housing managed by companies.
  They are exclusively residential complexes for the elderly in which the services are centralized and managed by the responsible company. Often in these contexts, both due to the high concentration of marginal situations in which the elderly find themselves, and for the lack of active life, problems of loneliness and physical and mental decay are accentuated.
- Houses in residential complex integrated with services (cohousing).
  These typologies represent an independent and voluntary choice of a way of life within a small community, preserving autonomy and remaining inside a partially protected environment. The integrated residential complexes have already been designed to offer mixed housing, suitable for both the elderly and other users (young people, students, etc.).
  Essential conditions for a co-housing are:

- it must be designed and built on the basis of a project shared with the future users in order to meet their needs (participatory design);
- it must have collective spaces for functional activities to develop a sense of community and stimulate relationships among residents;
- it must be organized and managed according to a set program of activities shared by the residents themselves.

Co-housing then allows to have an individual life in private accommodation enjoying the same advantages of community life, thanks to equipment enabling collective life and a fully shared daily management system.

This typology is very common in the USA and the North of Europe, however it is not traditionally recognised in other countries, such as Italy.

- Living alone or with a family

The elderly who are still in good health can live alone. However, reduced abilities often require older people to make changes in their living environments moving to a more supportive location, or to their family.

Smart applications for the elderly: some examples

Many studies reported that the use of information and communication technologies (ICT), such as computerized health device, home computers, Internet and other communication devices could help elderly people to improve their quality of life, as well as facilitate cost-effective care by both formal and informal caregivers (Heart and Kalderon, 2013). The ICT – based solutions can help old people to participate actively in community activities and to reduce social isolation. Therefore, ICT can be useful to improve the existing housing models, based exclusively on the passive technologies, converting them into smart housing.

Some examples of new applications for smart devices planned for the elderly are:

VINCLES Barcelona Care Net[1]: the project of the Barcelona City Council that won the first European edition of Mayors Challenge. The project is an application for mobile devices that will help elderly people to keep in touch with their circle of relations and with social or health care services. Family, friends, public sector employees and volunteers will be connected with each other and with the user, who will be able to select who they want in their network. The system will be available to elderly people who live alone, and to people who have some physical or mental limitations. Given the user profile, a very simple design has been selected that is easy to understand. *Vincles BCN* will extend the network of municipal support for the elderly. The programme's main innovation is that it combines public and personal care.

SOCIALIZE[2]: a hardware/software platform able to put the elder users in close contact with the community they live in through the use of new technology implemented in the elderly day by day context. The platform offers information and entertainment content geared to the needs and interests of elderly people. This contents will be provided in a barrier-free and user friendly way tailored to the age group and to different SOCIALIZE devices.

STIMULATE[3]: a platform which enables seniors to specify their assistance needs, to plan a trip, to optimise transport means and itineraries, to be provided with personal assistance while on the move, as well as to obtain local shopping recommendations and assistance. Advanced knowledge based on GIS technologies will be used for processing and personalising seniors' travel and shopping requests, optimising transport itineraries, providing travel assistance and securing health care support.

Smart houses for the elderly: some examples

The term "smart house" is generally used to refer to a modern house that combine innovative housing typologies with smart devices. A number of researchers have stated that the main

[1] http://www.ub.edu/senesciencia/noticia/1503/

[2] http://www.aal-europe.eu/projects/socialize/

[3] http://www.aal-europe.eu/projects/stimulate/

focus of smart housing design should be the development and the application of embedded advanced technologies in order to improve the quality of life, autonomy and a sense of security for the elderly and the disabled (Chan et al., 2009). Many examples of worldwide case studies, mostly experimental laboratories, take on the challenge of integrating ICT systems with the design of the house in a very high-tech approach (GhaffarianHoseini AH., 2013). In most cases, experimental and monitoring projects improve the comfort, communication, safety and health control of occupants through the analysis of their needs. Furthermore, some examples also focus on the social aspect, using ICT to connect the house with the community as shown below.

The Aware House (USA) is a living lab created by The Georgia Tech Broadband Institute Residential Laboratory based on the human-centered design approach. The promoters believe that "*the development and careful placement of appropriate technological support that can empower older adults to continue living in their own homes longer. They specifically focus on the effects of declining cognitive abilities on independent living, and the role information technology can play in augmenting those capabilities*"[4]. The principle of the house starts from the idea that living environments must be 'aware' of their inhabitant's needs and activities. It is based on ubiquitous computing that senses and recognizes potential crisis of users. Likewise, the University of Florida develops an intelligent lab-house, The Gator Tech House[5], to assist users with special needs and the elderly to enhance their quality of life. Many smart furniture and devices designed for comfort and energy efficiency, safety and security, activity monitoring, reminder/prompting technologies, fall detection systems, communication devices and biometric technologies (weight, temperature), create an environment that can assist and support the users. Several projects aim to maximize the use of active technology for assisting and monitoring the elderly at home. Infrared sensors can be associated with one or more activities: working in an area, having a meal, etc.

Some most recent examples based in the USA and the North of Europe have expanded the smart concept to the whole building and even to the outdoor environment enhancing the social aspect of life. For instance, in several UK, Dutch and Sweden residential housing settlements, the relationship between private and common spaces is one of the main goals of the project enhancing the quality of life of old adults.

From the state of the art analysis, the use of smart houses involves different benefits reducing the number of adverse incidents, providing support for conditions such as chronical illness and compensating individual's functional limitations. The main advantage of the smart house is that it allows the elderly to stay in a familiar and comfortable environment, realizing the goal of aging in place. However, if by one hand smart home technology can reduce social isolation due to the sense of security from having someone monitoring one's status, by the other hand can contribute to disconnect people from society. "*In trying to promote autonomy, we may end up promoting isolation. In keeping people in their homes past the point where they can interact with the community, we've essentially put them under house arrest*".[6]

From these considerations, our research question arises: how can smart homes solve the problems of elderly disconnection from society? We tried to answer the question through the proposal of a "smart care network".

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[4] AAAI Technical Report WS-02-02. (www.aaai.org)

[5] http://www.cise.ufl.edu/~helal/gt.htm#1

[6] U.S. Society: Census and Demographics, U.S. DIPLOMATIC MISSION TO GERMANY, http://usa.usembassy.de/society-demographics.htm

The “smart care network”: a proposal for the elderly of 2030

A kind of invisible “smart care network”, supported by ICT, unites the places of their everyday lives in a physical and virtual manner, enabling independent elders to simplify their way of life and avoid being a burden to their relatives. It would ensure services of autonomy and personal safety, as well as the physical and psycho-emotional wellness in a Smart Living Environment. The “smart care network” covers the two different dimensions of house/building and neighbourhood/city, and should permit the elderly modern technologies and services to enable them to lead an independent, up to date, but simple lifestyle.

In the last two decades, ICT has revolutionized our lives in term of access to information. However for elderly people the “digital barrier” still remain. Many researches has demonstrated that nowadays most of the “over 65” are not yet ready to take advantage of what the digital world offers (Warschauer, 2004). This “digital divide” will be solved in the next decades as the future older people will be grown in the digital era. Our “smart care network” is thought for this category of users.

The aim of the proposal is to design, implement and validate an innovative way of considering the elderly of the future (people born from the 1960s) and their needs.

The idea is to redefine the living environment by designing it on the basis of lifestyle habits, the degree of autonomy of the individual and personal needs. The home is connected both to the neighbourhood and to the city providing a link with: the community of other users with similar problems and needs, the health and social care infrastructures, local medical clinical centres, recreational activities and various other services. Fig. 1 shows how the innovative elderly living model can work. The elderly’s space is not only limited to the ‘home’ which, even if highly smart, can cause isolation. However, the interaction between “passive” and “active” technologies helps to break physical boundaries extending the ‘home’ to the whole city. Thus, physical distance is reduced by active technologies, prolonging ageing in place, where the ‘place’ includes the whole community.

The main needs of the elderly, as the literature shows, can be divided into three categories:

- psychological and physical well-being
- social interaction and self-sufficiency
- safety, security and accessibility.

Psychological and physical well-being are closely related, and the link becomes more important at the older ages with the increasing of chronic illness. As life expectancy increases and treatments for life-threatening diseases become more effective, the issue of maintaining well-being at advanced ages is growing in importance. There is an increasing research literature which suggest that psychological well-being may even be a protective factor in health, reducing the risk of chronic physical illness and promoting longevity. It has also been argued that psychological well-being should be addressed in measures of health valuation, and be considered in health care resource allocation.

Social interaction plays an important role in elderly people's life and new technology can help older people to maintain social contact, interact in new ways with family and friends, engage actively in their communities and share learning, skills and experience with others. The integration of ICT in the home and the urban environment can improve the social inclusion which helps older adults to maintain good physical and emotional health and cognitive function.

With regards to the safety and security needs, it is recognized that older adults are more susceptible to accidents and injuries than younger adults because of internal and external factors. Internal factors include the normal physiologic changes with ageing, increased incidence of chronic disease, increased use of medications, and cognitive or emotional changes. External factors include a variety of environmental aspects that present hazards to older adults. For these reasons, it is important to make homes and cities safer, through customized services and the use of new technologies.

Our "smart care network" try to satisfy those needs through the use of the active technology (upper part of the diagram of fig. 1), the passive one (lower part of the diagram of fig. 1) or by combining the two. For instance, a smart application can be used to do activities outside the house or to connect the user with other places/people whilst staying home.

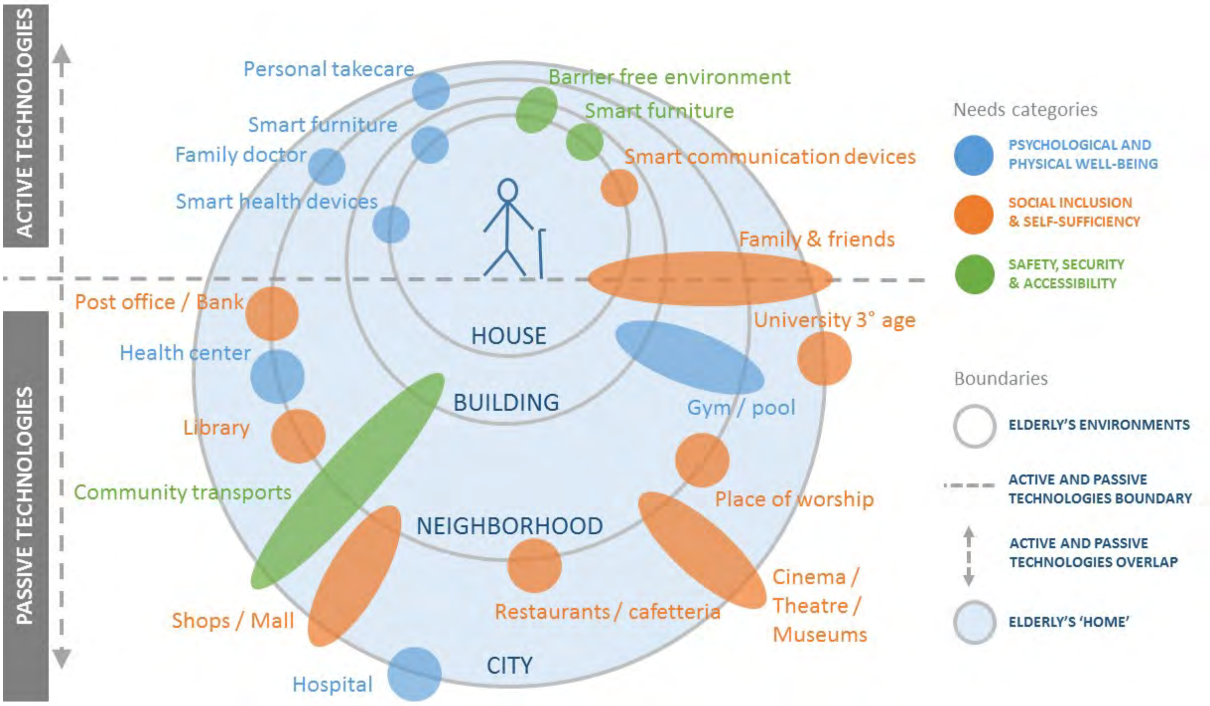

Figure 1. "Smart Care Network": an innovative senior residential model based on the integration of active and passive technology to fulfil the elderly needs and requirements.

The "smart care network" at the house/building level

A residential model for the ageing society based on the "smart care network" represents an alternative model to the elderly independent living often subordinate to the family's structure and needs and very common in countries like Italy and Asia. The experimental task of the proposal consists of an apartment for 5-10 older people aimed to improve their self-sufficiency. Users can make use of private spaces (room, toilet, kitchenette), semi-private spaces (living room, kitchen, dining room, laundry room, sickroom, outdoor green space) and semi-public spaces open to non-residents too (gym, coffee shop, playroom, place of worship, garden, terrace, etc.). Table 1 shows how the residential model aims to fulfil the three main elderly needs at the house/building level.

Table 1. Needs and strategies of the residential model based on the "smart care network" (house/building level)

NEEDS CATEGORIES	STRATEGIES AT HOUSE/BUILDING LEVEL
psychological and physical well-being	• smart furniture connected with the family doctor to monitor and support the elderly (ex. activity monitoring floor or mirror, infrared sensors); • smart devices such as a personal trainer board or wearable ICT objects for fitness and games which can stimulate mind and body; • specific applications for smart phones which help people monitor individual health problems;

	• the presence of a fitted outdoor space enhancing the quality of life and health benefits.
social interaction and self-sufficiency	• smart devices such as a personal trainer board or wearable ICT objects can help daily planning to encourage the elderly independency; • specific applications for smart phones allow the elderly to share special information, activities and events present in the apartment/building with a small group of friends and relatives;
safety, security and accessibility	• conventional house furniture is designed to satisfy elderly needs in ergonomic, flexibility, simplicity and safety terms from a shape, colour and material point of view; • the addition of smart furniture can optimize the home safety and accessibility (ex. activity assisting floor or mirror, infrared sensors).

The "smart care network" at the neighbourhood/city level

Users can join activities offered in the neighbourhood and the city from their home with the support of cooperatives, the municipality or other social agencies. In the same way, the three main elderly needs are taken into account at the neighbourhood/city level as shown in Table 2.

Table 2. Needs and strategies of the residential model based on the "smart care network" (neighbourhood/city level)

NEEDS CATEGORIES	STRATEGIES AT NEIGHBOURHOOD/CITY LEVEL
psychological and physical well-being	• smart street furniture for fitness and games can stimulate mind and body; • the proximity of a garden enhances quality of life and health benefit;
social interaction and self-sufficiency	• specific applications for smart phones allow the elderly to share special information, activities and events present in the neighbourhood/city with a small group of friends and relatives; • a small group of users can share useful collective services such as minibuses, concierge services, food delivery, private laundry, dog sitters, etc.
safety, security and accessibility	• the amount of economic intervention required by the city and social associations is less than in conventional assisted living situation.

Outlook and discussion

Our proposal aims to create a connection between smart homes, neighbourhoods and cities through ICT use, in order to answer to the specific needs of the ageing population to support independent elderly living. Understanding the needs of users is therefore crucial in order to offer the most appropriate service. However, elderly users are not a homogenous group and their needs vary significantly according to socio-demographic characteristics, gender, socio-economic differences or cultural area. In order to fill these gaps, one of our next objectives will be to make a more complete and detailed study of the user's profile which could help to create a needs-oriented approach for service development.

Further developments of the project require the collaboration between the property owners, the associations dedicated to helping the elderly, the older adults' communities and the industrial/research partners in order to define a complete framework of requirements and recommendations. The humanization principles as well as testing the functional, technological and economic adequacy of spaces are top priorities.

Conclusions

The new elderly living model aims to identify opportunities for experimentation in housing models as a valid alternative to health care residences and cohousing. The new objective becomes defining a new lifestyle model for senior people in a non-intrusive, customizable, adaptive and sustainable way. The proposal, mainly addressed to the elderly grown in the

digital era, should start from pilot case studies to develop, as ultimate aim, a widespread model for the next future (i.e. from 2030).
The proposal could also be an excellent solution for many older adults who do not wish to leave their accommodation, which could therefore be shared with friends, relatives or other people interested looking for a place to live. It can also be a dwelling situated in a traditional building, which would be renovated in order to be fully accessible and equipped with home automation systems and special assistive technologies.

Users lead an independent life, which can be supported at distance, through technological monitoring, or directly, through periodic visits, by private operators or active volunteers participating in the personalized care plan. These solutions can also have a great impact on reducing health care costs in the medium to long term, as they reduce the institutionalized hospitalization.

Hence, the aim of the proposal is to ease and improve the elderly's quality of life, giving solutions by connecting different environmental dimensions (house/building and neighbourhood/city) and combining active and passive technologies, in order to promote aging in place and avoid social isolation.

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Design to Thrive

The Almshouse Reimagined: challenging students in creating community

Alison Pooley[1] and Annabel Brown[2]

[1] Department of Engineering and the Built Environment, Faculty of Science and Technology, Anglia Ruskin University, Chelmsford, United Kingdom, alison.pooley@anglia.ac.uk;
[2] Annabel Brown Architect, High Street, Maldon, United Kingdom, info@annabel-brown.com

Abstract: For the past three years the authors of this paper have run a design project for second year architecture students entitled the Almshouse Reimagined. This collaborative project was proposed to studio tutors by a local almshouse charity to engage the next generation of architects in the social, political, and economic landscape of housing. The Almshouse Reimagined brief challenged students to rethink housing by designing a prototype Almshouse for Essex, questioning the housing needs of the local and wider community, and considering the opportunities presented by an ageing population. The challenge of the brief for second year architecture students should not be underestimated. The project constraints varied over the three years as did the site, a key constant being how do we create opportunities to build community. This paper explores how, through examining the almshouse typology in the early stage of their education, students are engaged in the pressing issues of our time, housing and the ageing population, whilst designing affordable homes that are protected from the ravages of the free market rented sector.

Keywords: Almshouse, community, housing

Introduction

On a cold day in early February 2015 second year architecture students studying in Essex were introduced to their design project brief for the forthcoming semester –The Almshouse Reimagined, a collaboration between the local school of architecture undergraduate course and the newly established almshouse charity, the Legacy East Almshouse Partnership (LEAP, n.d.). LEAP were keen to engage local architecture students in a design exercise that explored a prototype almshouse for Essex. Having a prototype almshouse presented the charity with an opportunity to use the proposals to test new sites with new communities and local planning authorities. For the studio tutors is represented an opportunity to get students thinking and designing for a client with constraints that were tangible, whilst engaging in wider societal debates focused on an ageing population and the housing crisis. The latter being more pertinent and immediate for students.

During the three years of running the project, during 2015, 2016 and 2017, the students and staff worked closely with the chair, vice-chair, and trustees of LEAP but also with almshouse residents, wardens, and the local community. Creating community is one of the challenges of a brief such as this, and the students responded by creating opportunities for sitting with views out across landscaped areas, quiet pedestrian routes, places to meet neighbours or talk over the garden fence in communal gardens, allotments, and outdoor rooms for afternoon tea. Before expanding further on the project outcomes it is worth placing the almshouse in context, and outlining how it differs from other housing types.

A potted history of the almshouse

In his 1955 text, Godfrey (1955) sets out the history and development of the almshouse from the medieval hospital. He draws attention to their architectural merit as well as their social history describing almshouses as “remarkable buildings, provided from a remote period for housing the needy and the aged” (Godfrey, 1955: 7) and that they “seldom lacked architectural merit and some of them were magnificent monuments of design and craftsmanship” (Godfrey, 1955: 15). This is where most people place the almshouse, a small, often elaborately crafted dwelling forming courtyards or quadrangles or a neat row of two or three in a quiet country village.

The almshouse is not unique to the UK and shares its history with the hofje (small courtyard house) of the Netherlands (Wilms Floet, 2016), and with the beguinage of the Low Countries. The roots of all these sit in philanthropy. The medieval response to those in need manifested in cloistered hospitals with refectories, chapels and modest dormitories. This continued throughout the centuries, as the need changed the typology largely did not, almshouses retaining many similar patterns of development as the early medieval plan. By the turn of the nineteenth century provision of housing for those in 'need' had developed, and continued to do so through philanthropic acts and utopian ambitions such as those of Octavia Hill and Joseph Rowntree. This provision developed from philanthropy to local authority, and led to what we now know as 'affordable housing', which used to be called social housing, and prior to that was just good old council housing. Worpole (2015) provides a concise history of the utopian dream of a planned society and its housing in his essay for the Swedenborg society, this is given as a key text to each student at the start of the project.

The merit of social housing and the concept of 'need', or the idea of the 'deserving poor' is not to be debated here other than to acknowledge that almshouses did exert control over their beneficiaries, with praise to the benefactor at worship on a Sunday often being compulsory. Many of the almshouses had additional restrictions on lifestyle – no drinking, no men, no women – and often required the residents to wear a uniform. The Royal Hospital Chelsea (left in legacy by Charles II) still does, and retains 'hospital' in its title, connecting it to its medieval roots. Chelsea, as with nearly all almshouses, has a restrictive admissions policy. Restrictions on who is eligible to become a resident of an almshouse range from; age - over 50 (or over 65 in the case of Chelsea), geography – having to be resident in an area for a certain period of time, or occupation – housing for retired teachers, carpenters, seamen. These restrictions on allocation of the houses are often borne out of the legacy of the benefactor. The distinction between being a resident as opposed to a tenant is crucial in almshouses, where residents pay a contribution to weekly maintenance rather than rent, and the charity is a registered provider rather than the landlord. The significance of this is discussed later in terms of contemporary issues.

A commonality among almshouses is that they provide housing for those in need in perpetuity, providing security and an ongoing potential to build community connections. This need for security and community remains evident today, and not just in terms of housing. As Godfrey (1955) highlights, with a population of only four million the medieval built response to 'need' was astonishing when compared with government responses to the current housing crisis housing and a population at just over sixty-five million.

Three projects and three years

Given such a rich and long history, the opportunity to work with a local charity to explore the almshouse typology further through a student project was exciting, especially when cast against the backdrop of the current housing crisis in the rented sector, the ageing population, and increase in single person households. In 2016, around 7.7 million people lived alone in the UK, the majority were women (ONS, 2016). The students, in the second year of their undergraduate degree, were faced by social and community aspects of the projects, this embedded them in current issues whilst simultaneously calling on a 1000 year old history. This section outlines the three projects undertaken over the past three years, and provides a brief exploration of the main issues and outcomes.

Chelmsford 2015

The first year the project was based in Chelmsford, where a notional site was chosen to test the development of the prototypes. The site, just over half a hectare and used as a car park, was located due south of existing almshouses built in 1933. This site offered an opportunity to explore the reuse of a car park for housing whilst linking the new almshouses into the existing infrastructure and almshouse community. The students were able to determine the density of the development, what type of housing to explore and imagine their own scenario for the client, all within a guiding principle that each unit was to be approximately $55m^2$ in floor area to attract funding from the Homes and Communities Agency (HCA). Some students chose to look at intergenerational housing, addressing their own housing needs and those of the local student population. Other issues raised through this project concerned views out over a busy road, material use, energy efficiency, existing community, rebuilding the street, access and transport to the city centre, water reuse, gardening, food growing and the inevitable three Bs – bins, bikes and buggies – although in many cases the buggy was replaced by the mobility scooter. As this was the first time running the project with the client (LEAP) their budget restrictions were absorbed into the brief for the students, a tight budget of £70,000 per dwelling delivered. Projected costs were kept in check by final year quantity surveying students who met three times during the twelve week semester with the architecture students to discuss the budget and exchange design ideas. The outcomes of that collaboration were mixed in terms of success, with the design process curtailed for some architecture students as costs appeared to take priority over design for the quantity surveying students (Pooley et al., 2016).

One and two-story buildings were designed to make use of the site and to address neighbouring housing developments. Proposals had community at their heart, reinterpreting the traditional ideas of central shared space. The traditional courtyard arrangement remained a feature in many of the projects where units were situated around landscaped areas and captured the ambition to provide a safer site with no public right of way, another feature of courtyard housing (Wilms Floet, 2016). Safety was one of the key issues that arose out of the ongoing consultation with LEAP and the residents and wardens at the neighbouring almshouses. Students were conscious of the need to address this without compromising access and views.

The students' proposals for the first iteration of the project, run in 2015, were presented to the National Almshouse Association (NAA) at a meeting of design consultants, the students went on to present again at the Housing LIN Eastern Region meeting later that year. On both occasions the projects were well received and the students commended for tackling such complex issues early in their architectural careers.

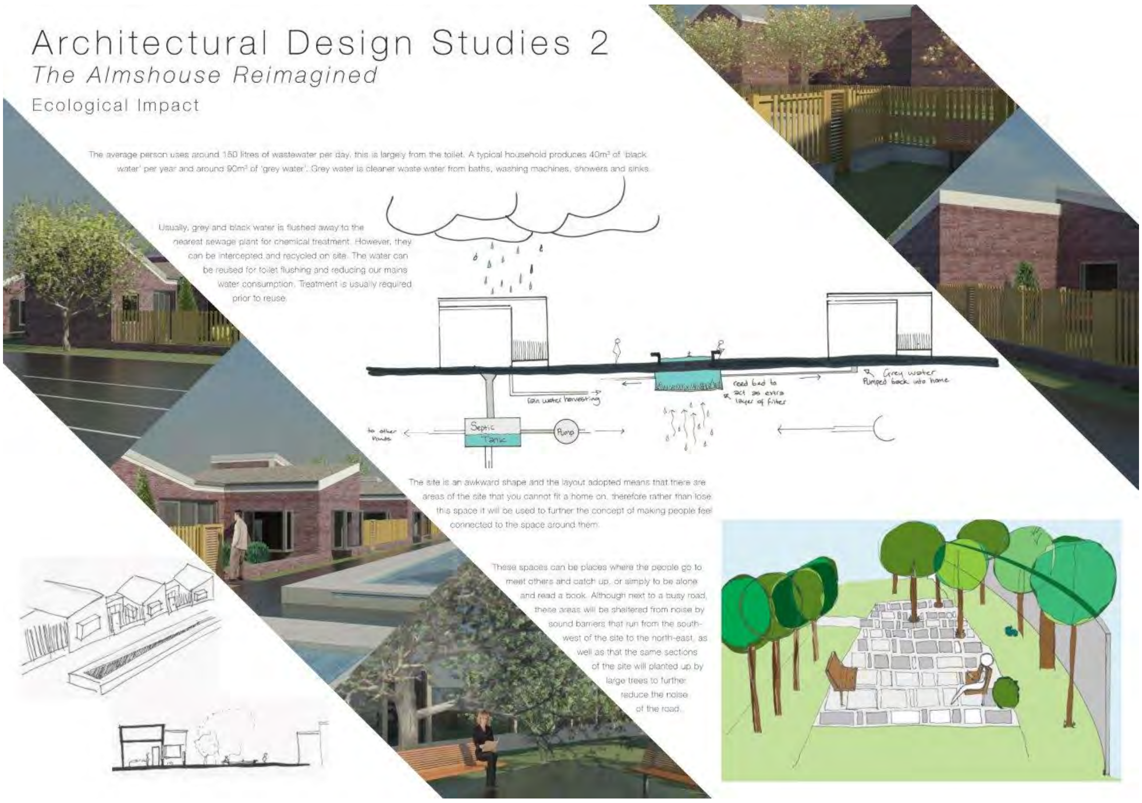

Figure 1. Student project for Chelmsford. Image: Jack Moloney

Colchester 2016

In the second year running the project the brief looked again at expanding an existing almshouse community. This time the issues were more complex. The site was a former bus depot, with a meter drop in level from the existing historic almshouses, with dwellings dating from 1791 and 1803 (and even older dwellings dating to 1678 across the road), to the new site. The bus depot had an existing planning application for student accommodation, and faced a reasonably busy road leading into the centre of Colchester. Once again LEAP acted as client, with the potential that this could possibly become a site for future almshouse development, rather than the fictional site used in 2015.

The restrictive nature of the budget in 2015 placed too much emphasis on keeping costs down, and curtailed creative exploration of housing types. In the 2016 iteration of the brief students were freed from budget constraints but given reasonable guidance from the client. The Colchester project also diverged from the original ambition in that this was a site specific project – not a prototype that could be located anywhere for the right price, inviting students to respond to the site and to knit the new almshouses into the existing fabric of Colchester, as well as the historic almshouses to the south. Issues that had arisen in the previous project – particularly those focused on mixed use and inter-generational living – came much more to the fore. One of the interesting questions that arose more through this project compared to the first year, was the nature of an ageing population. For students who were predominantly in their late teens/early twenties being over 60 or 65 seemed old enough, however if you were 65 in 2016 you were part of a generation that grew up on punk, and were probably still listening to it, you wanted to cycle, garden, go out, and have parties, have friends to stay as well as children and grandchildren. The project had to be about being active in an almshouse, as well as cater for the mobility scooter, or the potential of a mobility scooter in the future.

The response to this challenge, meshing old and new homes, old and new residents, old and new ideas about housing, onto a tight urban site whilst creating an oasis in the middle of a busy town, another feature of the Dutch hofje as well as the almshouse, demanded that students address issues of environment and sustainability beyond energy and materials, to consider what makes society, not only now but in twenty or fifty years. This is where the almshouse typology is useful, as it creates new visions for living in reasonably dense developments whilst looking towards exemplar models of community living that can be hundreds of years old, as with the almshouses adjacent to the Colchester site used in 2016.

Jaywick Sands 2017

The final project, and this year's iteration of the brief, was based in Jaywick Sands, Essex. Jaywick Sands has its own quite unique history, drawing on the utopian living experiments of other nearby communities of Essex (Worpole, 2015) as well as the arcadian vision of the plotlands movement and idealised rural living (Hardy et al., 1984). Jaywick has been heralded as one of the most deprived areas of the UK, and recent television programmes have focused on the less salubrious aspects of the seaside town. This project offered the most potential to actually get built as LEAP, once again acting as the client for the project, successfully secured a development site through the local authority.

Figure 2. Students and community discuss housing issues over lunch.

As in the previous two years, the students met with the local community, spent time with them at the lunch club in the community centre, and broke down some barriers (on both sides). As well as the social and economic pressures in Jaywick Sands there are the additional constraints of marshy land and developing below sea level with a risk of flooding. The site varies from the previous two projects in that it is a green field site but still has complex constraints. As the Jaywick Sands project matured so did the collaboration between our academic pursuits and the potential for the project to become a live project, for the student work to feed into the community and for all involved to realise the original ambition. Jaywick Sands raised the most controversial questions in terms of creating community, the view that we can design out certain behaviours or design in others harks back to the control and patronage of historic almshouse benefactors. Raising critical issues of how we design, who with and who for, and what potential environmental, social and economic futures can we address.

Figure 3. Student response to Jaywick Sands and future flooding scenarios. Image: Megan Pledger

Implications for pedagogy and practice

> We spend our lives in what were once the thoughts of architects. Today's thoughts make the world of tomorrow – an awesome responsibility (Day, 2004: 283).

As Day states above, there is an awesome responsibility in creating tomorrow's world, and one second year architecture students faced. Understanding the history and development of housing places that responsibility in its historic context, one that threads from the monastic communities of the middle ages, through the therapeutic communities of the twentieth century, to the present day via Victorian philanthropy and the Thatcherite commodification of home through the right-to-buy (Worpole, 2015).

One of the issues returned to again and again through all three projects is the importance of proximity to neighbours, knowing your neighbours and allowing those happenstance moments, the face-to-face interactions that build and maintain community. The almshouse has a human scale, and even though they are often small compared to other types of housing, residents are forgiving of them, they like to live there (Pannell et al., 1999), they also have potential for releasing development land, exploring new ways of funding and providing 'social' housing in perpetuity. Almshouses are not subject to the right-to-buy and it is hoped that they never will be. As Godfrey wrote over sixty years ago:

> it must be generally recognised that almshouses are performing a really useful function in the community, and all who value our art and history will agree that their preservation is a matter of real moment (Godfrey, 1955: 87)

Themes reoccurred over the three projects, through different sites and different constraints and challenges. One of the issues for us as educators with a keen eye on the future of the built environment, is how these projects feed into the development of the future professional. This is almost impossible to capture, but what is possible to identity is the reflective process students went through during the project. As they explored the needs of almshouse residents so they also explored their own needs, their family relationships, questioning what their grandparents would want, as well as what they might want when they are older. In this way the project has additionally become a personal reflection on the meaning of family and home, of social and emotional space as well as physical space.

There is a diversity amongst the students, different backgrounds, experiences growing up in different countries, and this has created a richness in the debate in the studio – who are we being architects for, are we designing for or with the community, what is the nature of home? These questions push the original agenda for LEAP and for the students, and offer an opportunity for inter-generational learning. There is a propensity in learning and teaching for students to become product focused rather than process focused (Sterling, 2001), placing an importance of the qualification or grade over the experience. Engaging in community based projects, in this case housing focused, and encouraging reflection on the process, learning retains the possibility to be process focused, generating a social learning as well as an environmental and ecological one as students recognise the importance of community, space to meet, gardens, places to sit, proximity to nature, creating opportunity for happenstance (Jones et al., 2012).

Figure 4. Proposal for an elevated pausing place for Jaywick . Image: Chris Theobald

When the students presented to the NAA in 2015 it was the first time architecture students had presented at that meeting, or to the NAA generally. Presenting at the meeting developed the students confidence far more than presenting in the studio, under more normal review conditions, would have done. The challenge for almshouse charities and the NAA is to how to bring forward the model in a way that meets the current demand for high density and high-rise living (Pannell, 2013). The debate is currently all too often focused on smarter living in smarter cities. There is no argument here for a return (?) to a William Morris style utopian dream, where we live with almost no furniture and have to forgo servants due to our small houses.

Future housing needs to be adaptive and responsive to changing needs, allowing for those downsizing, but still providing space for visitors. There is an argument for a focus on the person within the city, and retaining that focus will enable issues of health and well-being to be more fully addressed in future planning. There have been good examples of the almshouse remodelled for the twenty-first century, as well as an increased number of community projects getting planning permission for co-housing projects. However these projects, as with shared ownership schemes, still rely on a capital investment, something that the almshouse will never require from a resident.

Conclusion

> In the end there is no escape from architecture, no matter how modest or improvised. Behind any social arrangement there is a physical structure, a location and a landscape as well (Worpole, 2015: 56).

This project requires longer than one semester to explore, the complexity lending itself to a postgraduate project rather than an undergraduate one. Students experiencing working with a client for the first time can be restrict and guided or misguided to producing what the client appears to want or is already familiar with, rather than questioning the client, the brief, and the ambition of the project. This too is a consequence of asking students early in their career to tackle complex issues, understand a different community, a different generation, and even a different culture. A criticism of the project is that students have to tackle too many of these previously un-encountered issues. However by facing these issues they in turn reflected on their own position now, as well as their future role as an architect.

The challenge of this brief for second year architecture students should not be underestimated. However the reward of engaging with a real client to tackle a growing area of concern for all those involved in the built environment should also not be underestimated.

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Living with dementia condition in modern cities. Does urban renewal help vulnerable ageing population today?

Eleni Tracada[1]

[1] Department of Mechanical Engineering and the Built Environment, College of Engineering & Technology, University of Derby, Derby, United Kingdom, email E.Tracada@derby.ac.uk

Abstract: Current debate on ageing in urban environments focuses on how designers and planners develop age-friendly cities or communities. Since 2007, World Health Organisation has been supporting "active ageing by optimizing opportunities for health, participation and security in order to enhance quality of life as people age"; a global network of age-friendly cities has been launched and city councils are now engaging with local communities to transform urban areas into healthier and fully inclusive places. In 2014, the National Health Service (NHS), UK published their Five Year Forward View for three health, care and financial gaps to be closed. The NHS is currently running a new pilot long-term partnership with five cities' areas to develop healthier neighbourhoods by modernising services and integrating health and social care with welfare, education and affordable housing. The author of this paper and her colleagues formed a special cluster at their University to review recent national and international initiatives, such as the ones mentioned above. Their intention is to evaluate case studies and proposals related to ageing population with special needs and conditions, such as dementia, and apply innovative ideas of integration of arts not only in health places, but also in deprived neighbourhoods.

Keywords: Active ageing, urban renewal, dementia condition, health and social care, inclusive neighbourhood plan

Introduction

A year ago the author was invited by academics/colleagues from the College of Health and Social Care at her University to take part in initial discussions and presentations of ideas to be eventually developed as near future research projects. After two-three initial monthly two hour sessions, a cluster of researchers from a various disciplines was formed with interest in arts, architecture, social care and health (gerontology). Some participants were related to external organisations and/or attracted and brought in the cluster other people working or being involved with charity and arts' organisations, such as dementia carers' organisations or special theatrical groups often performing at the University dedicated theatre or other performance spaces run by local organisations, such as Déda (See further below). At the moment the cluster is known as an interdisciplinary group of people with the provisional title *Arts in Health: Arts in Dementia/Arts and Social Gerontology Research Cluster*. During the monthly sessions, the cluster coordinator and other members engaged in individual presentations of own research and experiences in previous years; these activities offered to all members of the cluster the opportunity to identify themselves in some particular research directions; a subdivision into four groups/work packs occurred with specific areas of interest. All four work packs are going to seek funding and develop project ideas related mainly to Arts and Health/ Dementia life condition. The four work packs have got provisional names:

Carers/Places and Spaces, Giving Voice, Intergenerational Aspects & Integrated Care and Participatory Arts as a Public Health Provision.

The author is co-Leader of the work pack called *Carers/Places and Spaces* with area of interest mostly on the following:

- Making the lives of carers better;
- Families for those cared for;
- What would self-help look like in relation to people with dementia;
- Performance & Spatiality (happening in space);
- Interactive/creative neighbourhoods.

Before starting writing specific bids, the cluster decided to spend more time and get involved in some initial activities and investigation on Dementia and Arts impact on people living with this condition. Last year, for example, the author and her colleagues had the opportunity to participate to a taster and consultation event on Arts and Dementia organised by Déda. They were invited by the Head of Dance Development & Learning of *Déda*, initially named as *Derby Dance* in 1991 and established as a local dance development agency based at Derby Playhouse. They became one of the first national lottery funded capital projects to move to new premises in 1997. The name of the organisation changed to *Déda* in 2008. This is the only dedicated dance house in the East Midlands region, acting as a local, regional and national resource for dance artists and the wider arts community. In their mission statement we find that:

> Déda's mission is to deliver an exceptional programme of dance, contemporary circus and outdoor work to as wide an audience as possible and be recognised for our outstanding contribution in the field of Dance Development and Learning.

(Déda, www.deda.uk.com, on 13/04/2017)

The author and her colleagues had participated in indoors and outdoors activities in which they tasted dance with people living with Dementia and their carers; they had the opportunity to get the feel of the project and understand the importance of participatory arts as public health provision for older people in the community and their carers, too. This particular experience led to decisions of integrating arts in the ordinary lives of both carers and people with Dementia condition in *Carers/Places and Spaces* work pack. The author's experience gained during this event also reinforced her belief that providing the conditions for free human flows in spatiality (happening in space) is more important than just designing spaces or places according to regulations only or being enclosed by rigid borders which are highly restrictive for people with special needs and conditions. Codes or signs of directions in urban spaces should be based mainly upon the principles established by the living conditions of the people rather than rigid grids and geometries. The author's experiences in urbanism and ongoing cooperation with experts in this discipline has affected her recent research projects and proposals enormously.

In December 2016 the Arts in Health: Arts in Dementia/Arts and Social Gerontology Research Cluster held a meeting during which a special workshop took place: a *Dementia Friends Information Session*. The session was delivered by one trained volunteer or Dementia Friends Champion and, at the end of it, all participating members of the cluster, including the author, became Dementia Friends (an Alzheimer's Society initiative) and created an account by registering at www.dementiafriends.org.uk; all members filled the *action mailer* and pledged an action. The author and her work group *Carers/Places and Spaces* pledged to campaign for change through teaching and research activities related to innovations not only in housing and services, but also in urban places; the aim is to improve the lives of people with dementia as well as the lives of the people caring and assisting them. This pledge was prompted by the Dementia Friends Information Session during which all cluster members learnt that *"dementia is not a natural part of ageing … it can affect thinking, communicating and doing everyday tasks; it is possible to live well with dementia; there is more to a person than the dementia"*(Leaflet: *Welcome to Dementia Friends*)

Case studies investigated to date - Discussion

The Carers/Places and Spaces group had also separate meetings to discuss details on research viewpoints and opportunities for funding. In August 2016 the author was asked by the cluster to present some inspiring case from the past; she created a presentation on *Historical past of hospices in Florence*; the presentation showed a historical route/path through the hospices/hospitals of Florence which is still working through the Santa Maria Nuova Hospital as urban connection and walk through. This particular communication path was once meandering unobstructed along piazza porticos, internal courtyards, through buildings and along corridors in order to connect ordinary people and their daily routine activities, such as markets and arts production, with healing places, such as the Santa Maria Nuova Hospital; the author revealed how art from the *Academia del Disegno* has been incorporated inside one of the oldest hospitals in Europe (founded by religious orders during 12th century) and how this integrations of arts has been contributing to carers and patients wellbeing.

Then, the author and her group carried out research on available literature and relevant publications and especially on latest developments on ideas and proposals for inclusive designs of entire neighbourhoods and inner-city or suburban areas as national and international projects. Thus, a first important document of great significance appeared; this is document published by the National Health Service (NHS) in England in July 2015: the *Forward View into Action*: Registering interest to join the healthy new towns programme. It is stated: *"The ambition of this programme is to go beyond existing good practice, developing new and creative approaches that offer the potential to make a substantial contribution to closing the three gaps* [health gap, care gap and financial gap]*"* (NHS, www.england.nhs.uk, on 14/04/2017, p2).

In this document mentioned above, we find that: *"Many areas already promote health and wellbeing through "place-shaping", including through better housing and urban design, and access to well-designed public spaces and facilities"* (NHS, www.england.nhs.uk, on 14/04/2017, p2). However, according to earlier discussions between local authorities and the NHS in 2014, these considerations were found not sufficient to tackle some important issues.

Thus, the *Forward View into Action* document in 2015 defines clearly the three core objectives as follows:

a. To develop **new and more effective ways** of **shaping new towns, neighbourhoods and strong communities** that promote health and wellbeing, prevent illness and **keep people independent**;

b. To show what is possible when we radically rethink how **health and care services** could be delivered, **freed from the legacy constraints** (i.e. existing services) that operate in other areas. This will support the **New Models of Care programme** by adding to the learning about how health and care services could be integrated to provide **better outcomes** at the same **or lower cost**;

c. **To accomplish the first two objectives in a way that can be replicated elsewhere**, making learning available to other national programmes as well as other local areas. (NHS, www.england.nhs.uk, on 14/04/2017, p2)

We have highlighted the most important points in the objectives above in bold fonts, because in our work pack we need to focus mainly on new radical models of care which will be integrated in new ways of designing and modelling not only new towns, but also renovating, or better, revitalising existing often rundown neighbourhoods in order to create strong communities of people of all ages and, especially keeping ageing population independent, without unnecessary constraints and barriers. All people should be cared to keep active whatever their conditions are, because, as Dementia Friends, we are fully aware that dementia is not a natural part of ageing; ageing population is mainly concerned about urban and housing designs that they may not offer them independence first and low costs of living.

In the 2015 *Forward View into Action*, NHS states that they cannot accomplish their three objectives above alone. Therefore they have invited areas with imminent population growth and housing needs to work with them to develop few *"radical new approaches to shaping the built environment"* (NHS, www.england.nhs.uk, on 14/04/2017, p3). We are citing here the first, third and fourth points on conceivable approaches, as stated in the same document, as we think that those should be also points of consideration to be encompassed into our own ideas and proposals:

- Building healthier homes and environments that support independence at all stages of life. We would like to explore new ways of integrating housing, care and communities to keep people independent and in their own homes. For those who do need support, more innovative residential care facilities may be combined with flexible housing options and step-up or respite care.
- Implementing a new 'operating system' for health and care that achieves "triple integration" between primary and secondary care, mental and physical health, and health and social care. This means developing a flexible health and care infrastructure that is linked to specialist care when needed, but provides many more services in the home, in primary care and alongside other public services. This infrastructure would also provide a strong platform for people to manage their own health and care, together with their peers and the voluntary sector, by making the most of mobile and digital channels.
- Creating connected neighbourhoods, strong communities and inclusive public spaces that enable people of all ages and abilities from all backgrounds to mix. Examples include 'dementia-friendly' design or ensuring that public spaces include features such as public toilets or benches that can make the difference between people being able to get out and about and being confined to their homes.

(NHS, www.england.nhs.uk, on 14/04/2017, p3)

At the time of this call in 2015, the NHS was seeking to establish some ambitious partnerships with local areas through which to develop healthier neighbourhoods and towns. Thus, they have invited expressions of interest from sites across England which are going to consider developments at different scales (from neighbourhood schemes as small as 250 homes to sites of 10,000 homes or more). The expression of interest had to be through a two pages long form; a lead partner had to be identified for the proposal, as well as other key stakeholders, including the Local Planning Authority. Where lead partners are not local authorities or statutory planning bodies, then, they may be housing associations, NHS Trusts and Foundation Trusts, private developers and land owners. In the *Registration of interest for healthy new towns programme* form, amongst the four questions, we can find that Question 3 asks how the proposed scheme is going to promote health and wellbeing through the built environment and how the NHS could support the partnership to deliver their ambition. Conversely Question 4 asks if there are any opportunities to redesign how health and social care is delivered in the proposed development and, again how the NHS could support the partnership to deliver this (NHS, www.england.nhs.uk, on 14/04/2017, p7).

In a recent article Urban Design magazine by Daniel McDonnell, Strategy Programme Manager, NHS England, at first we find out that *Forward View into Action* was also announced in a publication of Town and Country Planning Association & Public Health England in 2014 (www.tcpa.org.uk, on 14/04/2017). The same author (McDonnell, 2017) affirms that the built environment is not a routine territory for the NHS, but, because of increasing numbers of ageing population living longer and often in poorer health, the NHS recognises *"an opportunity to ensure that homes and neighbourhoods promote wellbeing and enable independence. Planning and urban design can play a crucial role in achieving this"* (McDonnell, 2017, p22). He also affirms that, across England, local authorities, providers and commissioners of health and social care are currently planning how they will deliver services jointly for the future; it is also noted that this kind of partnerships are also putting together Sustainability and Transformation Plans (STPs) and that, NHS Healthy New Towns programme has now selected ten demonstrator sites from 114 expressions of interest, as it was announced in March 2016 (McDonnell, 2017).

Although in most sites we see that a lot of effort was made, for example, for "walkable and cycleable community" developments, such as for Bicester Healthy New Town (McDonnell, 2017, p23), very limited information is provided about health and social care. Bicester Healthy New Town is also promoted as an Eco-Town (Figure 1.). It is noted that in some Healthy New Towns programmes, such as Barton Healthy New Town, Oxford, for example, some demonstrators of new, joined-up models of care are being developed as form of health and wellbeing centres, where several services will be co-located. However, as Strategy Programme Manager at NHS England, Daniel McDonnell discloses that the NHS has major programmes in progress *"to make healthcare provision more efficient and to improve the experience of patients by redesigning and joining up healthcare services, such as through Multi-Speciality Community Providers (MCPs) and Primary and Acute Care Systems (PACS) models"* (McDonnell, 2017, p23).

On the other hand, McDonnell refers to Barton Healthy New Town as a housing development which is being used as a driver to regenerate and connect with the existing neighbourhood; he also refers to Barton's proposals to convert an existing neighbourhood centre into a Healthy Living Centre, whilst the Oxford's John Radcliffe Hospital will bring services from the hospital to be embedded within the community. However Layla Mc Cay's article in the same issue of *Urban Design* makes more connections with what we are interested as research group inside our Arts and Dementia cluster, although the author explains a more holistic view on Designing Mental Health into Cities. (McCay, 2017).

The same author affirms that often urban living is related to mental distress; she also insists that: *"There are four main factors in urban living which can contribute to mental health problems: pre-existing risk factors, disparities, overload, and loss of protective factors"* (Mc Cay, 2017, p25).

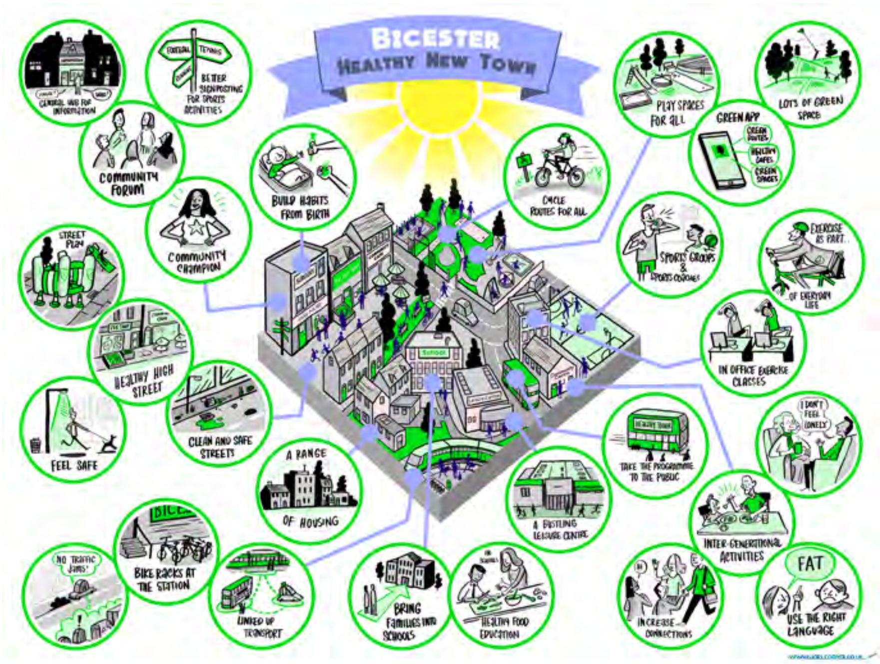

Figure 1. Stakeholders' visualisation of the programme for Bicester Healthy New Town (Source: http://www.oxfordshireccg.nhs.uk/your-local-area/localities/north-east/bicesters-new-healthy-town-programme/)

Layla McCay also refers to activity in daily routines which is one of the most important urban design opportunities for mental health. According to this author, exercise can *"reduce stress and anxiety, and help to alleviate some of the symptoms associated with ADHD, dementia, and even schizophrenia"* (Mc Cay, 2017, p27). By referring to creating pro-social places, McCay is convinced that urban strategies should *"facilitate positive, safe, natural interactions amongst people and foster a sense of community, integration and belonging"* (Mc Cay, 2017, p27).

Figure 2. New York City: An outdoor public garden courtyard hidden within the Noguchi Museum (Source: https://www1.nyc.gov/assets/ddc/downloads/DDC-Guiding-Principles-2016.pdf, p102)

Layla McCay is the Director of the Centre for Urban Design and Mental Health which was founded in 2015; this is a global think tank with main intend to explore opportunities to design better mental health into cities. This means that experts' and designers' main concerns should be towards better integration of urban design and mental health promotion, although this happens rarely in city policy making and planning. McCay praises only New York

City's *Design and Construction Excellence 2.0 Guiding Principles*, as one example, addressing mental health meaningfully. For example, on page 102 of the Guiding Principles (www1.nyc.gov/assets/, on 14/04/2017), we can see an outdoor public garden courtyard hidden within the Noguchi Museum in Astoria with the purpose to promote a design for Therapeutic Environments (Figure 2.)

Developing age-friendly cities is one of the main concerns of World Health Organisation (WHO) since 2002; three important publications/reports from 2002 to 2007 were produced and disseminated around the globe. In WHO *Global Age-Friendly Cities: A Guide* in 2007, we see that three issues require particular attention:

- First, recognising the diversity of cities and the implementations for the 'age-friendly approach.
- Second, developing new forms of 'urban citizenship' which recognize and support changing needs across the life course.
- Third, creating opportunities to involve ageing populations more effectively in the planning and regeneration of neighbourhoods.

(Buffel et al, 2012, p606)

Several authors (Buffel et al, 2012) believe that making cities more *age-friendly* will require radical interventions for involving older people as key actors in setting the agenda for future urban development; they should not be invisible in the implementation of urban regeneration, for example. It is also noted that there is need to develop strategies with awareness of contrasting issues faced by different ethnic groups, people with particular physical or mental health needs, etc.

Conclusion

The author and her colleagues in Carers/Spaces and Places group are currently considering and studying documents and reports produced for the Australian Housing and Urban Research Institute (AHURI) at University of Tasmania and University of Adelaide in June 2015 (AHURI Final Report No. 242). The main reason is that the author is currently engaging with and also working in a partnership action group with local authorities, housing associations for social and private housing, social workers, health services and other relevant NGOs in order to investigate on a rundown urban area in which issues related to all ages inhabitants have been identified. In particular, this area will be a pilot scheme for research and proposed solutions for intensive neighbourhood regeneration; an increasing ageing population with health and other problems, such as extreme poverty, has been identified in that area and mainly supported by youths often unemployed.

The author found out that Designing for Older People in the AHURI report (www.ahuri.edu.au, on 13/04/2017) and relevant attachments show that a variety of scenarios needs more inclusive interventions in housing and re-organisation of deprived areas. In the scheme to be piloted by researchers of the author's team and the local authority, there is a lot to be done as initial investigation at first, as many elderly people are still to be diagnosed for any mental health issues and other conditions, such as dementia. Whatever the condition, all people deserve to live well for the rest of their lives, including carers. Therefore, all our team has pledged for change starting from a small area and with intention to promote ideas at regional and national level in the next couple of years. This is not an ambition only; it is a professional challenge that we have duly pledged, as we are also planning to carry out extensive consultation with people with dementia and family carers by following the example of section 4 in the AHURI report mentioned above.

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Design to Thrive

Co-production and Resilience in a Brazilian Social Housing: the case of Shopping Park Neighbourhood

Simone Barbosa Villa[1], Fernando Garrefa[2], Fionn Stevenson[3], Karen Bortoli[4]

[1] Faculty of Architecture and Urbanism and Design, Federal University of Uberlândia, Uberlândia, Brazil, simonevilla@yahoo.com;
[2] Faculty of Architecture and Urbanism and Design, Federal University of Uberlândia, Uberlândia, Brazil, fegarrefa@yahoo.com;
[3] School of Architecture, University of Sheffield, U.K, f.stevenson@sheffield.ac.uk;
[4] Faculty of Architecture and Urbanism and Design, Federal University of Uberlândia, Uberlândia, Brazil, karencrbortoli@gmail.com.

Abstract: Current rapid social and climatic changes require urgent revisions of urbanization strategies globally, to reduce environmental and social impacts and develop the resilience of built environments. The poor condition of the architecture and urban situation of affordable housing in Brazil substantially affects the inhabitants of these developments. Despite this, people keep adapting their habitats, surviving the unexpected, and (re)inventing themselves according to their needs. This demonstrates their resilience, which is considered as an adaptive capacity to recuperate and regenerate from impacts (natural, social, physical). This paper presents the methods and results of the research "Adaptability and Resilience in Social Housing developments through Post-Occupancy Evaluation and Co-production[1]" as a project between a Brazilian and a UK University and a local community. This project engages with a Brazilian social neighbourhood named Shopping Park, where advanced Post-Occupancy Evaluation and Co-production techniques have been applied, aiming to co-produce knowledge about this social housing development. Data collected enables improvements on Shopping Park neighbourhood and future projects, in order to develop the resilience of families in social housing programmes and minimise social and environmental impacts derived from this sort of development in the future.

Keywords: Resilience; Adaptability; Co-production; Social Housing; Community; Post-Occupancy Evaluation.

Introduction

People are familiar with dealing with disturbances in the natural course of life around the world for many centuries, but there are distinctively modern phenomena underway now conditioning those events: urbanization, globalization, and climate change (Rodin, 2015). The current social and climatic changes require revision in urbanization strategies worldwide. Accelerated urbanization causes urban problems such as housing shortages, inefficiency of transport systems, inadequate disposal of waste and environmental depredation, among others. Climatic disasters are increasingly large, affecting urban systems (physically and socioeconomically) and involving major human and environmental losses. Such disasters

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originate from a junction between the climatic event, predatory human activity and the vulnerability of what is exposed, namely the urban systems (IPCC, 2014).

In developing countries, the low quality of architecture and urbanism increase the social vulnerability, which afflicts particularly people struggling to purchase their own house, who end up living in precarious conditions. In an attempt to meet this deficiency, the low standards defined by government housing programmes, such as the Minha Casa, Minha Vida (MCMV) in Brazil, has led to the provision of inadequate housings for its inhabitants. Self-made interventions at the houses by residents, without any planning or technical assistance, risk their safety, waste resources and excessively burden the family income. Relating to the MCMC Programme, it is a government initiative to try solving the housing deficit by targeting a specific segment of the population, divided into social housing (0 to 3 minimum wages) and medium income range (until 10 minimum wages).

According to Villa et al (2013), the usual peripherization of these housing developments makes people dependent on motorised transport in order to access their workplace, educational and health facilities, among others. This scenario increases the negative effects of climate change due to the high rate of waterproofing the soil and the extensive use of non-renewable energy sources (Rubano, 2008; Rolnik, Nakano, 2009). These factors end up socially, economically and environmentally weakening people who benefited from these government programmes, making them more vulnerable to any impacts.

The resilience in social housing developments is related to the adaptability of the housing units to the impacts experienced. Their resilience is verified when the reaction to the imposed adverse conditions overcomes a state of perturbation. This resilience is further defined by the ability of a system to absorb changes, self-organize and thrive by increasing its capacity of learning and adaptation (Cumming, 2011). In other words, it is the ability of a community to adaptively respond to change rather than simply returning to a pre-existing state (Maguire & Cartwright, 2008). Resilience, however, needs attention in a context of accelerated world population growth, which reproduces unsustainable urbanization models.

Case Study

This paper presents the first results of a research project named "[RES_APO 1] Method of analysis of the Resilience and Adaptability in Social Housing Complexes through Post Occupancy Evaluation and Co-production", developed by the MORA housing research group from FAUeD, Federal University of Uberlândia/UFU and the People, Environment and Performance research group from The University of Sheffield School of Architecture. In order to understand resilience in social housing, it is necessary to first know the vulnerabilities and potentialities that characterize a specific study area. Thus, as a main contribution, this work discusses the resilience in Brazilian social housing developments based on a real case study involving co-production with residents and other actors

The *Shopping Park* neighbourhood is just south of Uberlândia city at Minas Gerais State in Brazil (Figures 1, 2). *Shopping Park* was chosen as the study area as the first site in Uberlândia chosen to produce over 3.000 housing units from the MCMV Programme, within the income bracket 1 (0 to 3 minimum wages) during the 2010-2013 period. Post-Occupancy Evaluation (POE) and Co-production techniques emerged as appropriate methodological tools to obtain socio-environmental and behavioural data as well as information about vulnerabilities and potentialities of the study area. The objective was to produce a concise database from the performance using a variety of tools, as summarized on Table 1. The overall aim was to outline the scenario of resilience at *Shopping Park* neighbourhood as well as to develop methodological procedures applicable to another contexts, in order to evaluate and improve their local resilience.

Figure 1. Uberlândia Location. Source: Authors, 2016

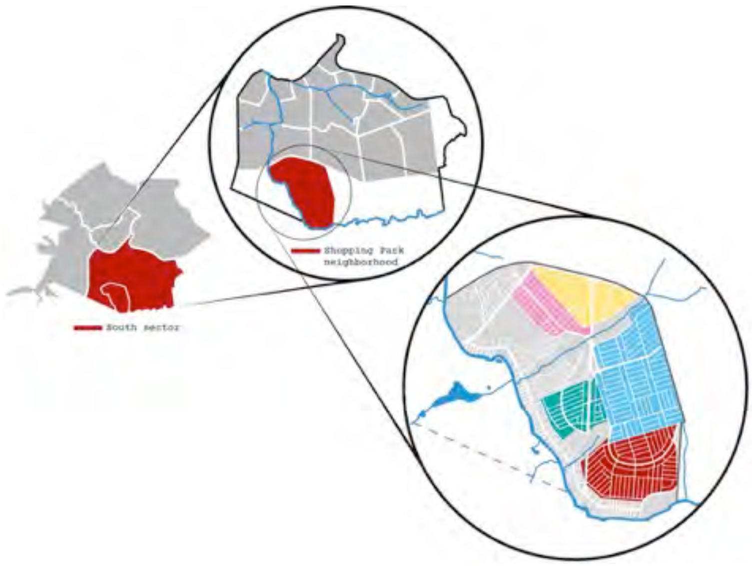

Figure 2. Sector, Neighbourhood and Allotments division. Source: Authors, 2016.

Table 1. Used tools on evaluating Shopping Park Neighbourhood. Source: Authors, 2016.

DIGITAL QUESTIONNAIRE
Description: Quantitative method collecting data from a series of questions answered by users. Recommended when there are a variety of people involved in an evaluation process. Its main advantages are: being quick; deals with a larger group of respondents and/or vast areas; impartial answers; anonymity allows safety and a great freedom of response; and greater uniformity in the evaluation. **Means:** Digital, through tablets taken to the study area.
WALKTHROUGH
Description: Quanti-qualitative method of analysis based on measuring and descriptions, and qualitative identification of positive and negative aspects of current environment. Includes measurement of climatic features, evaluating temperature, lighting, ventilation and acoustics on the unit scale. The analysed themes are: i) Surroundings, ii) Allotment, iii) Housing. **Means:** Script on paper and textual and photographic recording.

CO-PRODUCTION
Description: Qualitative and participative evaluation method where the impartial researcher works as a facilitator to co-produce management of space by all stakeholders. An alternative way to face unmet public demands and provide effective access to the city (Petcou and Petrescu 2015). A co-productive partnership between academics and non-academics can generate significant public benefits. **Means:** Script on paper, textual and photographic recording, meetings and group dynamics.

Developing the Tools and Techniques

Three central elements were analysed in the case study: (i) BUILT ENVIRONMENT (building complex, taking into consideration the scales of the district, neighbourhood and unit, and the relation of impact between the built and natural environments; (ii) AGENTS (agents that interfere with the local social dynamic); and (iii) USERS (residents of the complex). These elements were divided into 5 categories: general characteristics, climatic and natural order, physical-architectonic order, physical-urbanistic order and socioeconomic order.

From that division the most suitable tools were developed to collect information for each category. As an example, the physical-architectonic order was subdivided in 10 aspects to be evaluated: Design, Construction System and Materials, Maintenance, Services, Internal Layout, Adaptation and Refurbishment, Adaptation for Commerce, Comfort, Privacy and Previous Housing. For each one of these aspects, the required information was listed, for example “what are the main pathologies of the house?” or “what materials do the dwellers use on renovations?” on the Construction System and Materials aspect. The Questionnaire aimed to answer the first question while the Co-production would address the second one. Based on that mapping customized POE and Co-production tools were developed in order to collect information to properly portray the study area.

The evaluation as a whole intended to study the social, functional, behavioral and environmental issues of the built environment. Given the significant differences and specificities of the aspects to be analysed concerning resilience, the elected tools have been conceived to work complementarily. This multiple methods approach aimed to adjust any variances and inconsistencies in the obtained data as well as to strength conclusions when convenient or discard those less representative. This is because information collected through a single technique is usually seen as suspicious or even to present dubious results, since all methods have positive and negative points, and their applications depend on the characteristics of the problems addressed in the object in question (Marans and Ahrentzen, 1987).

Co-production is a relative new approach to address social, environmental and economic challenges. It can question and change the power relationships within the contemporary built environment, its production, governance and maintenance, to enable more sustainable and resilient communities (Stevenson & Petrescu, 2016). It goes much further than ‘user involvement’ or ‘participatory design’ and engages directly with the principle of equal partnership. This transforms the dynamic between those who use our built environments and those who produce it, where all stakeholders pool different types of knowledge and skills, based on lived experience and professional learning.

The specific contribution of co-production as a method allowed the research team to present their initial findings to the local residents in the case study neighbourhood as well as other activists working in the area, and to gain their insights into the findings in relation to their own concerns. Co-production requires careful facilitation to ensure that all voices are heard and treated as equally important. The use of mapping as a technique to capture stakeholders concerns in a neighbourhood is a powerful facilitation tool, providing everyone with the chance to stake out their issues and priorities, and to then debate and prioritise these collectively via the mapping exercise itself.

POE and Co-production at Shopping Park Neighbourhood

Three years after completion, the case study housing development shows clear signs of inefficiency and failure, contrasting to the original purpose of the government programme. The aim of giving people a "dignified living" failed under different constructive, social and environmental issues. Despite this, the resilience of the environment and the human being seems to coexist within cracked walls, bumpy roads, and streams clogged with litter (Figure 3) with thousands of people inhabiting this space and seeking ways to make it better. In other words, despite the deprived conditions of its houses and facilities, families are actually happy to live there (60% are happy about their neighbourhood).

Figure 3. Photos: Shopping Park's failure. Source: Gollino, 2015 (first); Arantes, 2015 (second); *Correio* Journal, 2013 (two in the right).

In order to evaluate the resilience of *Shopping Park's* residents, questionnaires were completed in 40 selected houses located in a pattern allotment of 200 houses - a good sample of 20%. The questionnaire was organised in five main aspects (related to the 5 categories previously mentioned): family characteristics, surroundings characteristics (neighbourhood), allotments' characteristics, housing characteristics and, finally, energy efficiency and sustainability.

From the application of Walkthroughs in four houses previously interviewed, reaching a 10% sample, the intent was to carry out an analysis supported by normative attributes (benchmarks), allowing the verification of the current environmental situation. The categories analysed were: i) Surroundings; ii) Lot; iii) House Unit, under sorted aspects as accessibility, urban furniture, vegetation, privacy, dimensions, sectorisation and performance of climatic features indoor, among many others.

Three Co-production workshops took place at Shopping Park neighbourhood. The first was entitled "Collective Coffee", the second as "II Meeting Renew Shopping Park" and the third as "III Meeting Renew Shopping Park". In each co-production session of 15 participants on average, new strategies were implemented in order to obtain information related to the main complaints of the residents in respect to the neighbourhood; the residents' favourite places in the neighbourhood; and the choice of effective actions to improve at the neighbourhood. Although participants expressed their willingness to improve their neighbourhood, with up to 48.6% unhappy about the amount and quality of available facilities, their complaints constantly focused on the housing unit issues. Most of the residents (82.5%) agree the main issue is the terraced house without acoustic insulation between different houses and rooms, leading to the difficulty of 25% on get along with neighbours, and another 31.6% not satisfied in terms of privacy among residents.

The fact that the houses were the main source of problems of the neighbourhood suggested that the activation of resilience at *Shopping Park* neighbourhood should first happen through the resolution of some significant pathologies, as described next.

Co-production to Activate Resilience of Built Environment

During the evaluation process, key factors drew special attention following validation through at least two of the tools, with the Co-production sessions becoming the moment when these factors were highlighted. Moreover, the negative impact they cause extends to the environmental, social and physical spheres, signifying them as strategic issues to be studied as well as improved within the local community seeking increased resilience. They represent the main vulnerabilities and sources of potentialities in the housing units. These factors, in order of significance, were: poor acoustic perform, lack of green areas, high rates of soil sealing, waste disposal and the high costs involved on refurbishments. Table 2 summarises information collected about each factor in the evaluation process, endorsed in the Co-production sessions. Some positive aspects derived from the resolution of each issue are also listed, and are considered as attributes able to improve the resilience of the neighbourhood.

Table 2. Main Issues at Shopping Park Neighbourhood. Source: Authors, 2016.

POOR ACOUSTIC PERFORMANCE
Description: More than 48.7% of respondents of the questionnaire are dissatisfied with acoustic performance. If fact, 47.5% refurbished their houses in order to solve technical problems and another 45%, to improve privacy. Performance analysis has confirmed constant noise through the shared walls between homes, which are clearly audible in most homes. In the first Coproduction, some residents reported suffering from depression due to the lack of privacy. **Positive Impacts Post-Intervention:** Increased privacy would favour the improvement of relations between neighbours, such as a better performance of activities such as relaxing, sleeping and working.
LACK OF GREEN AREAS
Description: 67.5% of the inhabitants interviewed feel the lack of landscaped areas inside the lot (52.5% paved the external area), though most of them have chosen not to invest on its cultivation due to the difficulty of maintenance and / or lack of knowledge about gardening techniques, as well as due to the scarcity of financial resources (Co-production 1 and 2 outcomes). **Positive Impacts Post-Intervention:** The practice of gardening can promote a network of learning, exchanges and trading between neighbours, as well as the planting of seedlings can be done in order to promote evaporative cooling of the house.
HIGH RATES OF SOIL SEALING
Description: 52.5% of the units evaluated have the external area paved beyond the 80% allowed by law (and 67.5% enlarged the coverage), configuring a situation of fragility to floods and landslides, once there is no vegetation enough to stabilise the soil (50% of houses visited on walkthrough analysis). Additionally, the settlement of the allotment without correct stabilisation of sloping ground increases the vulnerability of houses, since there are several cases of structural collapse due to landslides (Co-production 1). **Positive Impacts Post-Intervention:** The replacement of cement paving by alternative more absorbent materials would guarantee the soil stability and improve the microclimate while allowing the evaporation of wet soil.

WASTE DISPOSAL
Description: 92.3% reported that they have changed something from the original design of the house. Self-build is currently a recurring practice in the neighbourhood. The Walkthrough revealed the presence of construction materials stored on the front and sides of the lots, as well as on the backs and sidewalks. 65% of those interviewed reported having witnessed neighbours depositing waste incorrectly in public areas. In the first Co-production residents complained about the presence of soil, sand and other construction materials attracting insects and rodents inside the house, impairing their hygiene and healthiness. Moreover, waste harms the general appearance of the neighbourhood, which disturbs 23.7% of the interviewees. However, it is estimated that 57.5% of the interviewees carry out the separation of recyclable waste and the oil from other organic waste. **Positive Impacts Post-Intervention:** The proper disposal of waste improves life quality by ensuring the maintenance of clean, healthy and habitable spaces. Moreover, the cooperation in the collection, storage, administration and treatment of recyclable and organic waste may be a source of monetization, and consequently, community empowerment.
HIGH COST INVOLVED ON REFURBISHMENTS
Description: From the Co-productions it became clear that frequently the refurbished houses have as a builder resident, reducing the labour costs, which is not the reality for most residents. It is a consensus among residents that the high cost involved often makes it impossible to carry out quality reforms compatible with their needs, and they end up using cheaper materials of inferior performance and low durability. The main target of interventions in the house refers to the construction of walls by 77.55% of the interviewees, followed by the expansion or creation of covered areas (57.5%) and paving of the external area (52.5%). The laudry, kitchen and living room are the spaces whose size less satisfy the residents, being the target of up to 40% of them on refurbishments. **Positive Impacts Post-Intervention:** The dissemination of alternative constructive technologies and materials could allow reduced building costs. Furthermore, cooperation on administration and execution of refurbishments, through sharing of skills and labour, may become a source of income for those willing to conduct Workshops, joint efforts, etc.

Conclusion

By applying POE and Co-production techniques guided by the concept of resilience at the Shopping Park neighbourhood, it was possible to confirm that there are already high rates of resilience and adaptability there. Despite all the adverse impacts experienced by the residents regarding their poor quality neighbourhood, block and housing unit, they keep adapting and seeking for alternatives to improve their built environment. However, this is only partially resilient since little is done to develop truly sustainable and replicable solutions, due to the residents being restricted in their ability to overcome fragilities in a palliative way.

What is lacking in the neighbourhood is collective engagement and knowledge about the vulnerabilities and potentialities of the whole area. The partnership between academics and non-academics aims to share information collected as well as personal skills in order to empower the community to resist the impacts that will be imposed over time and thrive when faced to a situation of precariousness, in the next phase of co-production. The evaluation process developed at Shopping Park neighbourhood enabled the Co-production sessions as environments for experimentation and opportunities to take a close look at the community and its more acute vulnerabilities. The initial approach has focused on the issues at the urban scale, and has highlighted a difficulty to enable wider community projects, since the individual housing unit is the main source of dissatisfaction. In fact, the next stage of the research project intends to focus on the housing unit scale in order to activate wider resilience at *Shopping Park* neighbourhood.

In face of the obtained outcomes, it was realised that co-production can actually contribute to improve the resilience of place. Considering it, this research project will be continued and the co-production actions at Shopping Park defined in two subsequent stages (2 and 3) that will be carried out in 2017 and 2018. The academics are leading efforts to engage another stakeholders, such as NGOs and industry, working in the local area, in order to identify possible resources (e.g. building materials, re-used materials) to promote physical interventions to improve the housing in the first instance.

Small actions properly designed, and working directly with the residents themselves, can lead to big changes in the long term. After all, it is remarkable that simply carrying out a study with the community in fact have already improved people's perceptions and behaviours (Mallory-Hill et al, 2012) - after each Co-production session people presented more indepth information about their context. This confirms resilience as a natural and evolving attribute of human beings, sometimes needing encouraging to be fully reached, seeking to build more sustainable cities.

Acknowledgements

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Sound

PLEA 2017 Conference

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Soundscape assessment of a water feature used in an open-plan office

Zanyar Abdalrahman[1] and Laurent Galbrun[1]

[1] Heriot-Watt University, School of Energy, Geoscience, Infrastructure and Society, Edinburgh, UK. Email: za113@hw.ac.uk and l.g.u.galbrun@hw.ac.uk

Abstract: Research has shown that noise masking systems can successfully mitigate the detrimental effects of noise in open-plan offices. This paper provides a new approach to noise masking in open-plan offices, through the use of water sounds generated by real water features placed inside a work space. The effectiveness of water sounds in masking noise, especially irrelevant speech, has been extensively examined in previous laboratory experiments. The current paper builds upon the findings achieved so far, by extending the study into real-life settings. A water feature, designed in accordance with preference findings obtained previously, was installed in a medium sized open-plan office (12 workstations). A satisfaction questionnaire (focusing on the soundscape) was distributed prior to the installation of the water feature, to assess the work environment in the absence of any noise masking system. Then, another satisfaction questionnaire was distributed, after the water feature had remained in the office for a period of 3 weeks. The results obtained from both questionnaires suggest that the water feature had a positive effect on the soundscape assessment of the open-plan office, as shown by an increased level of subjective satisfaction that confirms laboratory findings. According to these empirical results, carefully designed water features could substitute conventional noise masking systems, with the added benefits of being affordable and contributing to an increase in the aesthetic value of the space.

Keywords: noise masking, water sounds, soundscape.

Introduction

Despite the economic benefits associated with using open-plan offices, there is a growing body of scientific evidence suggesting that open-plan offices increase workers' dissatisfaction and cognitive workload (De Croon et al. 2005), cause fatigue and difficulties in concentration (Pejtersen et al. 2006), and cause subjective impairment of work performance (Haapakangas et al. 2008). Dissatisfaction with the acoustic environment, i.e., background noise and lack of speech privacy, has repeatedly been highlighted as the main cause of the above problems (Bodin Danielsson & Bodin 2009; Jensen et al. 2005; Sundstrom et al. 1994). Irrelevant speech coming from co-workers is one particular factor that has been identified by numerous studies to have the most negative impact on the comfort level of workers. This finding is so robust and consistent over many studies to make it safe to state that little improvement can be achieved in the acoustic environment of open-plan offices without a thorough understanding and proper treatment of this type of distraction (Venetjoki et al. 2006; Virjonen et al. 2007; Hongisto 2008; Haapakangas et al. 2011; Haapakangas et al. 2008).

Masking sounds have been reported to help in reducing the intelligibility level of speech, and thus, decreasing the detrimental effects of this type of noise. Examples of masking sounds are pink noise (Ellermeier & Hellbruck 1998; Schlittmeier & Hellbrück 2009), white noise

(Loewen & Suedfeld 1992) and filtered pink noise whose sound pressure level decreases 5 dB per octave band (Venetjoki et al. 2006; Haka et al. 2009; Jahncke et al. 2011).

Among the studies reviewed, only one study used a water sound as a mean of masking speech in open-plan offices, and its findings were promising. Haapakangas et al. (2011) examined the effect of five different masking sounds on workers' performance: filtered pink noise, ventilation noise, instrumental music, vocal music and a spring water sound. The spring water sound was most beneficial in terms of both subjective (satisfaction) and objective (performance) indicators, results that none of the other masking sounds could acheive.

On the above ground, extensive laboratory research started to examine the audio-only and audio-visual preferences of water sounds and their likely impact on people's satisfaction and performance level. The results obtained were encouraging, and therefore, it was decided to further extend the research by placing a water feature in an open-plan office for a period of 3 weeks. This allowed examining the longer-term effect of having a water feature in a work space through a satisfaction questionnaire.

Design of the water feature

A water feature (dimensions, 48H $\times$ 45W $\times$ and $\times$ 49D cm) was purchased and modified to meet the criteria set out by previous stages of the current study regarding the audio-only and audio-visual preferences of different water features used as speech maskers. A cascade-like water feature was highly preferred, and therefore, a 3-step cascade was purchased and modified to provide a pleasant sound and visual apearance. The modified water feature is shown in Figure 1.

Figure 1. Three-step cascade used in this study.

After modification, the sound quality of the water feature was subjectively evaluated and the sound pressure level of the water feature was measured in the highly insulated anechoic chamber of Heriot-Watt University. The average sound pressure level (SPL) 1 meter away from the centre of the water feature was measured to be 45.5 dBA.

The open-plan office

A medium sized open-plan office with an area of 56.3 m^2 (dimensions, 7.60W $\times$8.75L $\times$2.90H m) was selected for the water feature to be installed in. Figure 2 shows a photograph of the office and its plan with dimensions. The open-plan office was located in the William Arrol building of the Edinburgh campus of Heriot-Watt University. The office accommodated 12 workstations clustered into 3 groups of working area. The finishing material of the walls was plaster and the ceiling was made of absorbent ceiling tiles. The water feature was placed at the middle of the shorter side of the space on a 0.7 m high table, as shown in Figure 2. This position was carefully chosen to minimise the space taken up by the water feature while making it both visible and audible from most of the workstations. The equivalent sound pressure level, $L_{Aeq,}$ of the background noise in the absence of employees at each workstation was measured over a period of 15 seconds, with and without the water feature in operation. The space averaged L_{Aeq} was 33.5 dB (empty room but equipment switched on) without the water feature, and rose to 39.3 dB when the water feature was switched on.

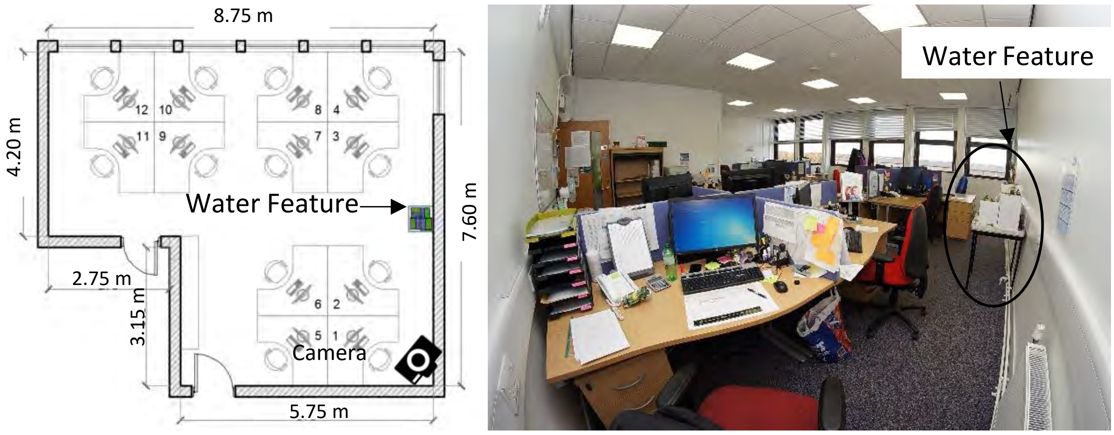

Figure 2. The open-plan office where the water feature was placed in.

Questionnaire

A modified version of the GABO questionnaire (Pierrette et al. 2014) was used to assess the initial noise environment in the open-plan office and to measure likely effects that the water feature could have on people's perception of their work environment. The questionnaire was divided into two parts, Part 1 and Part 2. Part 1 was distributed before installing the water feature, and Part 2 was distributed after the water feature had been in the space for a period of 3 weeks. The two parts were mostly identical apart from a few extra questions concerning the water feature added in Part 2.

The first section, "General information about you and your workstation", gathered background information such as age, gender and length of time working in the office. The second section, "Assessing the physical environment of your work area", assessed the employees' satisfaction with their physical working environment. This section consisted of 14 items, half of which (i.e., 7 items) measured satisfaction relating to control/privacy aspects, and the other half was about comfort/functionality aspects of the workspace.

The third section, "Assessing the noise environment of your work area", assessed employees' noise environment. Participants rated the general perceived noise level and then stated the level of annoyance caused by noise in the space. Participants were also asked about the perceived frequency of two noise sources: intelligible speech and unintelligible speech.

The fourth section, "Your perception of the sound environment", was dedicated to measuring people's perception of the sound environment in the work space. The section included questions measuring different aspects of the sound environment such as pleasantness, the possibility of concentrating on tasks, the possibility of having a meeting without distracting others, working uninterrupted, and the possibility of having private conversations. Ten questions specific to the water feature were added to this sections in Part 2 of the questionnaire, to measure how people perceived the water feature and its sound.

An 11-ponit numerical scale was used in the current study where 0 stood for "very dissatisfied/strongly disagree", and 10 stood for "very satisfied/strongly agree". The main aim of the study was to examine the likely effects that installing a water feature has on people's satisfaction and perception of their work environment, small differences being more easily detectable in an 11-point scale than, for example, a 5-point Likert scale.

The fifth section, "Your relationship with noise in general" assessed how people reacted to noise, i.e., their sensitivity to noise. This section was a shorter version of the noise sensitivity questionnaire (NoiseQ) developed by Schütte, Sandrock et al. (2007), which consists of 12 items divided into 3 subscales, namely, *sleep*, *habitation* and *work*, with 4 items in each subscale. Participants stated their level of agreement with each item on a 4-point numerical scale with 1 representing "strongly disagree", and 4 representing "strongly agree". The answer to each question was then quantified from 0 to 3 and used to calculate the average noise sensitivity score. A score of less than 1.11 is considered as not being sensitive to noise, while a score of greater than 1.63 is considered as being sensitive to noise (Schütte, Marks et al. 2007).

Statistical analysis

Data was analysed using IBM SPSS Statistics for Windows, Version 22.0. Given the small sample size (N=14), and the violation of the assumption of normality of most scores (checked using Shapiro-Wilk test and Normality Q-Q plot), it was decided to adopt non-parametric tests for the statistical analysis. The Wilcoxon signed-rank test, which is the non-parametric version of the related *t*-test, was used for comparing scores between the two parts of the questionnaire. Bias-corrected and accelerated bootstrap method, BCa, was used to derive robust 95% confidence intervals, which are reported in square brackets throughout this paper.

Where appropriate, the effect size, *r*, is given, which is a standardised measure of the size of effect observed. The effect size is not readily available in SPSS, however, the z-scores provided as a part of the Wilcoxon signed-rank test can be converted to *r* (Field 2013).

Procedure

Part 1 of the questionnaire measured the initial satisfaction level of workers within their work environment. After all participants had filled out Part 1, the water feature was installed in the space. The water feature had remained in the office for 3 weeks (5 days/week), before Part 2 of the questionnaire was distributed. Participants were asked to keep Part 1 until after Part 2 of the questionnaire was distributed. Then, both parts were collected together. The responses obtained from both parts of the questionnaire were analysed and compared to identify any change in people's satisfaction level and their perception of the work environment.

Participants

Fourteen participants (2 males, 12 females) filled out the questionnaires. These were staff members of Heriot-Watt University, aged between 24 and 61 yr (M = 39.86 yr, SD = 11.64 yr). The average time participants had spent in the open-plan office was M = 1.39 yr (SD = 1.15 yr), with an average attendance of M = 2.86 days per week (SD = 1.55 days per week), due to staff rotation. The score obtained from the noise sensitivity questionnaire revealed that, on average, participants were moderately sensitive to noise (M = 1.58, SD = 0.70). A slightly higher score was obtained when the sensitivity to noise was calculated based on the *work* subscale with an average score of M = 1.66 (SD = 0.64).

Results

Satisfaction within the physical work environment

Bias-corrected and accelerated bootstrapped 95% CIs are reported in square brackets. The results from Part 1 of the questionnaire revealed that participants were satisfied with their physical work environment, M = 7.06 [6.55, 7.64]. When the analysis was made separately for the two underlying subscales, the results indicated that participants were more satisfied with the comfort/functionality aspects of their work environment, M = 7.58 [7.09, 8.09], compared to control/privacy aspects, M = 6.53 [5.88, 7.24]. The difference in satisfaction between the two subscales was found to be statistically significant (z = 2.984, p = .001, r = .564).

After the water feature was added to the space, global satisfaction level within the physical work environment increased, M = 7.28 [6.71, 7.92], however, this increase was not statistically significant (z = 1.615, p = .115, r = .305). Having said that, the water feature significantly increased the satisfaction levels within the subscales comfort/functionality, M = 7.84 [7.35, 8.36] (z = 2.530, p = .012, r = .478). The satisfaction level within subscale control/privacy also increased, M = 6.71 [5.91, 7.56], but the increase was not statistically significant (z = 1.104, p = .295, r = .209).

The increase in satisfaction level can be attributed to 3 items within the physical work environment, namely *Item 1* "Noise environment" and *Item 2* "The cleanliness of your work area" within the subscale comfort/functionality, and *Item 3* "Possibility of concentrating in your workplace" within the subscale control/privacy. When the scores of Items 1, 2 and 3 were compared before and after installing the water feature, it was revealed that the water feature significantly increased the satisfaction level for Item 1 (z = 2.803, p = .004, r = .530), and Item 2 (z = 2.041, p = .041, r = .386), but the increase was not statistically significant for Item 3 (z = 1.876, p = .074, r = .354).

Satisfaction within the noise environment

Employees perceived the noise level in the office not to be high, M = 4.43 [3.14, 5.97], nor annoying, M = 4.14 [3.14, 5.21]. Furthermore, the water feature did not seem to have any effect on the perceived noise level, M = 4.29 [2.93, 5.64], nor annoyance, M = 4.36 [3.21, 5.43]. Statistically, no significant differences were detected for perceived noise level (z = 0.426, p = .672, r = .081), and perceived annoyance (z = -0.412, p = .680, r = -.078), before and after installing the water feature.

Participants assessed the frequency of occurrence of two noise sources, intelligible speech and unintelligible speech. Intelligible speech, M = 7.50 [6.64, 8.36], was perceived as being twice as frequent as unintelligible speech, M = 3.79 [2.14, 5.36]. After the water feature was added, the perceived frequency of intelligible speech dropped to M = 6.21 [5.36, 7.00], and the change was statistically significant, (z = -2.326, p = .027, r = -.440). On the contrary, the water feature resulted in an increase in the perceived frequency of unintelligible speech, M = 4.57 [3.14, 5.93], yet, the increase was not statistically significant (z = 0.784, p = .523, r = .148). This is understandable as the water sound must have masked a portion of the intelligible speech and made it unintelligible, hence the increase in the perceived frequency of unintelligible speech. Looking at the r values, it appears that the water sound had a much larger effect on reducing the frequency of the intelligible speech in comparisons to its effect on increasing the frequency the unintelligible speech. This implies that in addition to masking a portion of the intelligible speech and making it unintelligible, another portion of the intelligible speech might have become inaudible, hence the inequality in effect sizes.

In terms of annoyance, neither intelligible speech, M = 3.93 [2.57, 5.29], nor unintelligible speech, M = 2.43 [1.21, 3.86], was perceived as being excessively annoying. Furthermore, the water feature did not have a significant impact on reducing the perceived annoyance level caused by intelligible speech, M = 3.86 [2.64, 5.00] (z = -0.276, p = .783, r = -.052), and resulted in an increase in the annoyance level associated with unintelligible speech, M = 3.50 [2.07, 5.07], yet the increase was not significant (z = 1.689, p = .109, r = .376).

Perception of the sound environment

This part of the questionnaire included 6 questions, 2 of which examined people's perception of the sound environment, while the remaining 4 were related to the possibility of carrying out certain office-related activities within the sound environment. As shown in Figure 3, the water sound resulted in an increase in scores for all 6 questions.

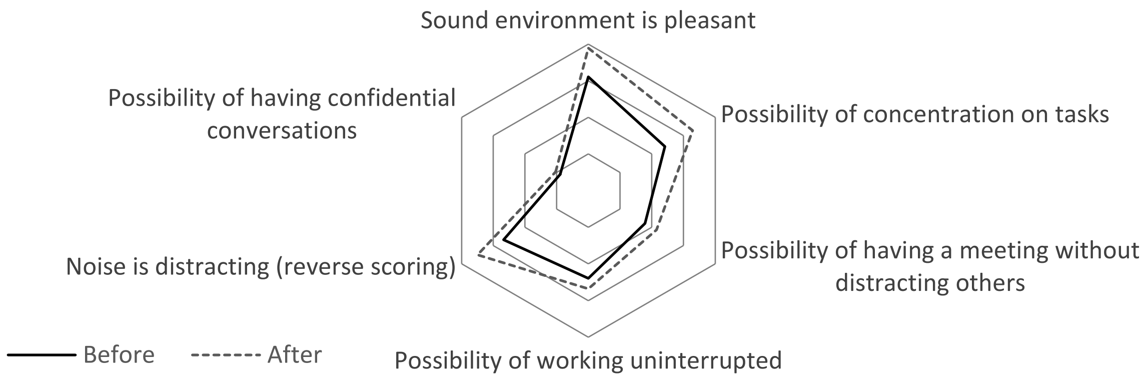

Figure 3 Satisfaction within the sound environment.

Participants perceived the sound environment of the open-plan office to be moderately pleasant, M = 6.21 [5.21, 7.14]. The inclusion of the water feature in the work space significantly increased the pleasantness level, M = 7.79 [6.86, 8.71] (z = 3.244, p < .001, r = .613). The sound environment was perceived as not being particularly effective in helping people to concentrate on their tasks, M = 4.82 [4.07, 5.61], but this score significantly increased after the installation of the water feature, M = 6.57 [5.57, 7.64] (z = 2.807, p = .003, r = .530). This suggests that the water feature was effective in helping people to carry out certain tasks. Participant were also asked if they perceived the sound environment of the work space to be distracting, and the responses suggest that they did not perceive it as being distracting even before the water feature was installed, M = 4.64 [3.71, 5.64]; however, the water feature further improved the sound environment, M = 3.00 [1.93, 4.07], and made it significantly less distracting (z = -2.505, p = 0.014, r = -.474).

Despite a slight increase, no significant differences were detected in the possibility of having a meeting without distracting others (z = 1.111, p = .344, r = .210), possibility of working uninterrupted for long periods (z = 0.905, p = .563, r = .171), and possibility of having confidential conversations (z = 0.496, p = .664, r = .094). The latter was to be expected, as confidential conversations require a greater level of privacy that the water sound was incapable of providing.

Part 2 of the questionnaire included 10 extra questions concerning the water feature. The responses to these questions revealed that the water sound was very positively perceived as being pleasant, M = 9.14 [8.64, 9.57], as improving the sound environment, M = 8.57 [7.93, 9.14], and as being visually/aesthetically pleasing, M = 9.57 [9.29, 9.86]. Furthermore, the water feature did not cause people to feel stressed, M = 0.14 [0.07, 0.36], nor its sound distracted people, M = 0.14 [0.07, 0.36]. Nevertheless, the water feature did not seem to have helped people to carry out private conversations, M = 4.43 [3.07, 5.86]. Only 2 participants thought that the water feature increased the frequency of going to the toilet with an average increase of 2 times per day, and finally, 13 out of 14 participants preferred the water feature to remain in the space on a permanent basis. The last question was an open-ended question, for which the comments were all positive; "very pleasant", "it is a pleasant soothing sound", "the feature is lovely to look at". The responses to the above questions suggest that the water feature was highly appraised by participants with very little adverse effect on the number of times that people needed to go to the toilet.

Discussion

This study provided an insight into the use of a water feature as a noise masker in an open-plan office. Generally, participants were satisfied with their physical work environment, however, the inclusion of the water feature significantly increased the satisfaction level of the comfort/functionality aspects of the work environment. This increase in satisfaction level could mainly be attributed to an increase in people's satisfaction with the noise environment and cleanliness of their work area. The water feature significantly decreased the perceived frequency of intelligible speech, which shows its effectiveness in masking speech. This was further demonstrated by an increase in the perceived frequency of occurrence of unintelligible speech, although this increase was not statistically significant.

The water feature had a positive impact on people's perception of their sound environment. After the inclusion of the water feature in the space, participant perceived the sound environment to be more pleasant, more effective in helping them concentrate on their tasks, and less distracting. The water feature did not help people in working uninterruptedly, having meetings without distracting others, and carrying out private conversations. In that respects, it should be noted that a water feature, such as the one used here, is a fairly quiet masking system that can only be effective up to a certain limit. It cannot fully compensate the disadvantages associated to an open-plan office, but it can certainly reduce its adverse effects.

The water feature itself was highly appraised, most participants asking to keep the feature in the space permanently. The water sound was perceived as being highly pleasant too, and the feature significantly improved the sound environment and added an aesthetic value to the space.

It is worth mentioning that more statistically significant results (i.e., $p < .05$) would have been possible had the sample size been larger. In a few cases, the effect sizes of the water feature exceeded .30, but no statistical differences were detected. For example, the water feature had a *medium* effect size ($r > .30$) on improving the physical work environment, and the possibility of concentrating on tasks, with p-values greater than .05. An effect size of .30 could be practically meaningful. For instance, even only a 1% increase in the performance of employees would result in a saving of around £3500 per annum. This calculation was made assuming an average salary of £25000/year and 14 employees (1% $\times$ 14 $\times$ 25000).

Limitations of the study

This study was carried out to extend some laboratory findings into real-life settings. The small sample size (N = 14) limits the generalisation of the findings. The study is also based on a relatively small and quiet open-plan office where people were already satisfied before the installation of the water feature. It is not clear whether even more positive findings might be achieved in crowded and larger offices with less satisfied people. Having said that, statistically significant improvements in the work environment were still possible despite the small sample size. In many cases the magnitude of the effect size was still above .30 which is considered a medium effect size. The study indicates a great potential for water features used in open-plan offices to mask noise, making it an attractive topic for further research.

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Design of passive devices with natural ventilation and sound attenuation

Yoshiaki Ando[1], Aníbal Figueroa[1] and Silvia de Schiller[2]

[1] Bioclimatic Design Doctorate Program, Autonomous Metropolitan Univeristy, Azcapotzalco, Mexico City, Mexico, andoashijara@gmail.com, figueroa.anibal@gmail.com
[2] Research Centre Habitat & Energy and Consultant Professor, University of Buenos Aires, Buenos Aires, Argentina, sdeschiller@gmail.com

Abstract: Natural ventilation, one of the main bioclimatic design strategies, when applied for air conditioning and air changes for a healthy indoor environment, may introduce urban noise impacts. This problem, produced by ventilating indoor spaces in modern cities, may provoke stress and affect physical and mental health. Products in the international market offer reductions in noise intensity in selected sound frequencies allowing proper ventilation, but they are expensive and not widely available in emerging countries, affecting cost and implementation. The focus of this paper is the design of new and innovative proposals for local natural ventilation devices. The evaluation and validation procedure is implemented during design process to insure the device effectiveness in ventilation and sound attenuation. As costs to test design in specialised acoustics laboratories are high, both initial cost and testing subsequent modifications for design improvements, an experimental low-cost test facility complying with ISO 7235: 2013 standard was developed to allow effective testing of design proposals and evaluate devices which combine natural ventilation and sound attenuation. The paper presents the testing procedure adopted to evaluate two existing models with reference data and implementation of effective procedure to assess two conceptual industrial design proposals and compare the results.

Keywords: Natural ventilation, sound attenuation, insertion loss, design, experimentation, normative, devices.

Introduction

Ventilation is the process of providing or removing air from a space for the purpose to controlling contaminated air, humidity, or temperature levels. Natural ventilation is provided by thermal effects, wind or diffusion through doors, windows or intentional openings in buildings (ASHRAE, 2007). In the bioclimatic design, the wind is used to climatize without using mechanical devices, or to generate movements and renovation of the indoor air. This flow, not only changes the thermal conditions of the space, also directly affects the occupants generating a feeling of well-being (Fuentes, 2004; Serra, 1999).

The inhabitants of the cities, when acquiring a new home or workspace, are going to realize of the acoustic problems that can have until inhabiting it. For various situations, the inhabitants will have to adapt or get used to it (Field, 2010). It may not be a problem because the adaptive capacity of the human being. But many people fail to adapt, and this affects their quality of life, their mental and physical health. One of the implementations that traditionally are done to reduce the annoyances of the noise is to change or to reinforce the windows, sealing the infiltrations of air that allow the entrance of the noise. Many windows are completely sealed and do not allow natural ventilation, and the conditioning is solved by installing mechanical systems. This increases electricity consumption, therefore, increases economic spending and affects the environment.

There are natural ventilation devices that are classified into three types: passive, active and hybrids (De Salis et al, 2002). A state-of-the-art study of device types was performed (Ando et al, 2016). It was determined that the study of passive and hybrid type devices is relevant, since there are in the global market a great diversity of active devices that have an engine that induces the air. One problem with natural ventilation devices and systems is that they allow intrusion of ambient noise. Devices that are equipped to attenuate noise are few in the global market and expensive for emerging countries.

The objective of the research is to design passive natural ventilation devices with sound attenuation. To do this, it's necessary to develop an Experimental Instrument that allows rapid evaluations for design, reduces the costs of evaluation in the laboratory, and results are valid to predict performance. Different standards such as ISO 10140, "Acoustics: Laboratory measurement of sound insulation of building elements" were revised, but the laboratory conditions are very strict and the conditioning is expensive. Finally, the design of the experimental instrument was based on ISO 7235 as "Acoustics: Laboratory measurement procedure for duct silencers and air terminal units. Insertion loss, flow noise and loss of total pressure "(ISO, 2009), whose development is described below.

Methodology

ISO 7235 conforms to the type of devices that are of interest to design. The overall dimensions will depend on the type and measures of the devices by the technical specifications of the standard. Each element has its conditions to size. In the case of the present investigation, the minimum dimensions of the commercial devices (louvers), which are 300 mm x 350 mm were taken as reference, reason why the instrument reaches a measure of 3550 mm length.

The conditions of the standard for the location of the instrument aren't strict. This can be in an acoustic non-isolated site in its entirety. Consideration should be taken to avoid contact with vibrations, not to be exposed to sources of noise and to a high level of ambient noise, which does not have extreme variations. In order to perform with the conditions, the noise generated in the test duct must be at least 10 dBA above the background noise, and there're no disturbances in the measurements by the external noise. For this purpose, the experimental instrument was designed with adequate acoustic insulation requirements in its construction.

Theory of Insertion Loss according ISO 7235

ISO 7235 defines that "Insertion Loss (D_i) of the Test object (device to be evaluated) is the reduction in the level of acoustic power in the Conduit Behind the Test Object due to the insertion of the Test Object in the Conduit instead of a Replacement Conduit "(ISO, 2009).

This means that the experimental instrument will measure the reduction of acoustic power in a duct without any element that interferes with the passage of sound. The device to be evaluated will then be installed. Sound pressure is measured at five different points on the back side of the sound source (Conduit against Test Object) with the microphone. From the insertion loss formula: $D_i = L_{WII} - L_{WI}$

L_{WI} is the level of acoustic power in the considered frequency band, which propagates along the Test Conduit when the Test Object is installed, and L_{WII} is the level of the acoustic power in the considered frequency band, which is propagated along the Test Conduit, when the Replacement Conduit replaces the Test Object.

Basic components and Model

The design of the experimental instrument was based on the specifications of ISO 7235 (Figure 1). The instrument consists of seven basic assembling sections for the measurements: 1. Module for the speaker; 2. Conduit in front of the Test Object; 3) transitions to fit the dimensions of the Test Object; 4a. Test Object; 4b. Replacement Conduit; 5. Conduit against Test Object; 10. Anechoic Termination (Figure 2).

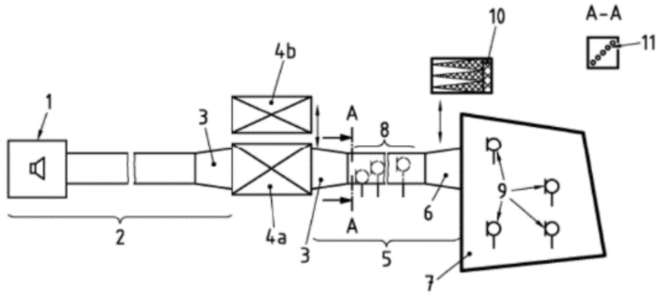


Figure 1. Examples of test facility layouts for non-airflow insertion loss measurements. (ISO 7235)

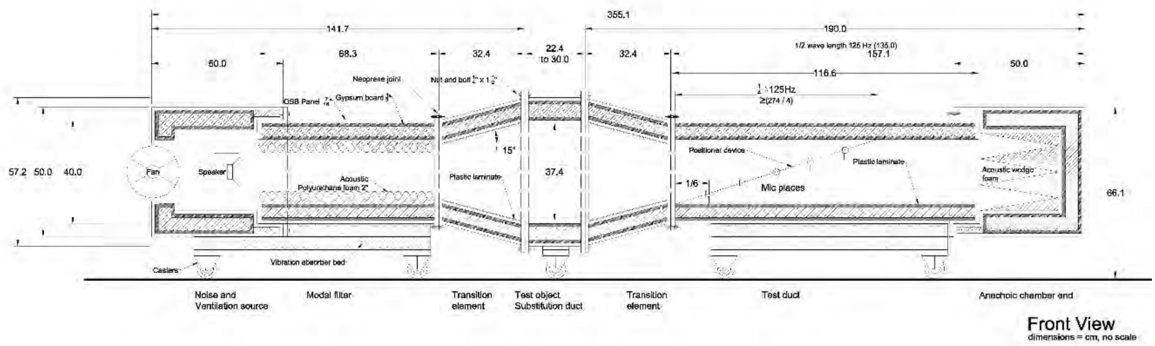


Figure 2. Diagram of elements according to ISO 7235 (Realized by the authors).

It's important to mention that the instrument can end up with a Reverberating Chamber or an Anechoic Termination according to the characteristics of the test object and the needs of the measurements. In the present case, the devices will be measured with the Anechoic Termination.

The Experimental Instrument was designed and constructed with the following characteristics:

1) The Module for the speaker is a cube built with OSB board 11 mm thick on exterior and interior walls, two layers of 11 mm gypsum board, 51 mm of mineral wool filler having a final thickness of approximately 100 mm. It has a 50 mm polyurethane foam acoustic insulation plate with "egg carton" texture to cushion the vibration transmission of the speaker that is suspended on the foam. The speaker used is a Bose Soundlink 15859, which has a frequency range of 88 Hz - 10 kHz with Bluetooth connection, and allows wireless connection.
2) The Conduit has the same characteristics as the module for the speaker. The minimum dimensions of 200 x 200 mm were applied inside the duct. The conduit engages a flange-type at the adjustment transition to the test object.
3) The Transition will increase from the size of the Duct to the dimensions of the Test Object.

4) The Test Object is a module in which different variants of devices to measure can be mounted. Based on the measurement of a frame of 300 x 350 mm, a perimeter of 50 mm is added for a seal of 200 mm mineral wool lined of fabric to facilitate the changes and the wool isn't torn. Both elements are installed in a frame constructed in the same way as the Conduit. This element has a frame that functions as a flange and facilitates changes in test (4) and replacement (5) Conduits for the necessary comparative measurements.
5) The Replacement Duct is an empty frame that allows to measure how the sound is transmitted directly from the speaker to the five microphone locations.
6) The Duct behind the Test Object is constructed in the same way as the preceding elements, with the difference that its interior is lined with an acoustic reflective material. Melamine plastic laminate was used. In this module, the microphone will be in five proportional positions from its ends.
7) The Anechoic Termination has the same constructive characteristics of the modules, in its inner wall that finishes the flow of the sound is lined with a plate of polyurethane foam of 50 mm with texture of wedges directed towards the speaker. On its back side, it has a double layer of mineral wool and a detachable top where a 6 mm x 38 mm x 1200 mm aluminum strip is inserted through a slot that acts as a microphone holder, and at the same time as a positioner with marks of the measures that place it in the five positions from the outside.

Both test ducts are mounted on casters to facilitate assembly and disassembly of the test and replacement elements, because they have a considerable weight due to the density of the materials (Figure 3).

Figure 3. Construction of the experimental instrument ISO 7235: 2003 (Realized by the authors).

The microphones are Dayton Audio brand (Ohio, United States of America) specific for acoustic measurements with USB connection. The OmniMic V2 Precision Measurement System software was developed by the same company. The microphone and the software were tested in an anechoic chamber and in a reverberant of the Center of Acoustic and Luminotechnical Research of the National University of Cordoba, Argentina. They were compared with measurements of a Brüel & Kjaer class 1 sound level meter and a Behringer Ecm8000 microphone with LabVIEW software from National Instruments.

The frequency spectrum was close to that registered by LabVIEW, with calibration the measurements can be taken as reference for the level of design tool, but if they are required to be certified, they must be tested under laboratory conditions and equipment.

Reference Models

Two models of louvers with acoustic design were built in workshop, the design specifications of commercial models were taken. The materials used were 22-gauge carbon steel sheet on exterior faces with folds, multi-perforated 2 mm diameter carbon steel sheet on inner faces, 50 mm thick mineral wool filling, metallic liquid paint finish. The manufacturer's minimum module of 300 x 400 mm (Figure 4) was considered.

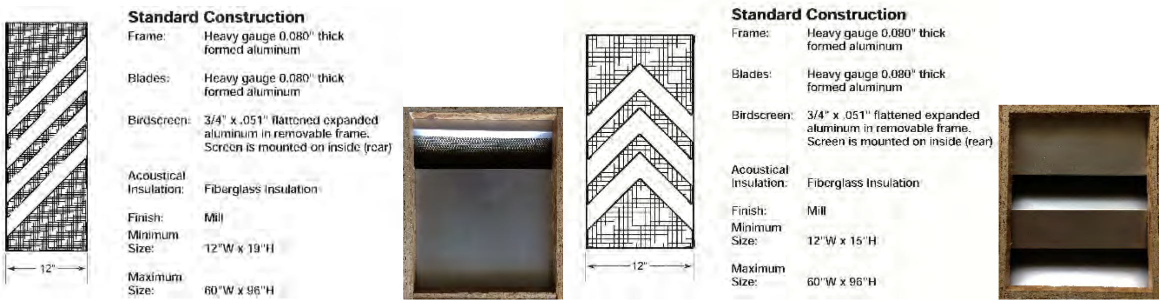


Figure 4. Analog reference models Greenheck Mod. AFJ-120 and AFS-120 (www.greenheck.com) Model A and Model B respectively (Realized by the authors).

Implementation for the evaluation of two conceptual proposals

To produce the proposals, materials traditionally used in architectural construction were considered: porcelain ceramics, wood, mineral wool, acoustic polyurethane boards, phenolic foam boards. Manufacturing processes changed according to the design and quality characteristics proposed. Diamond drills were used for the drilling of the ceramic plates and for the plates of the absorbent material.

A 20 mm OSB frame was constructed with the same exterior dimensions of the reference devices. Inside, MDF guides and spacers of 3 mm were implemented that allow the exchange of elements to be able to evaluate different configurations. Using laser cutting made templates with different configurations of holes, to combine those that allow the adequate flow of air and to be able to attenuate some frequencies. The reflective plates and absorbent materials were drilled with the templates.

According to the design hypothesis, the combination of materials with geometric configuration will achieve sound attenuations near the background noise level, allowing the air flow through the device. This air flow will allow, through a cross ventilation, the cleaning of interior air of a room. For the comparative level of airflow, the same area of entry of the outer face of the devices was maintained (Figure 5).

Figure 5. Images of the conceptual proposals evaluated. Model C and Model D respectively (Realized by the authors).

Ventilation tests

To be able to measure performance of ventilation, an experimental device was implemented for this purpose. Which consists of the emulation of a ventilation duct, it is divided with grooves each 50 mm to let slide the templates and combine different thicknesses of materials and deviations of flow. The duct at one end is fitted with a three-speed propeller fan, which was fitted with a dimmer to set the speed required for the evaluation.

The wind speed measurement was recorded with a Kestrel 4500 anemometer, which was fitted with a support to keep it fixed in the duct. The capture of results was a picture of the screen with digital photographs.

Method of recording results

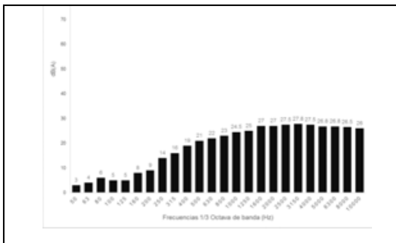
The acoustic test results must be recorded according to the recommendations given in section 7.8. of ISO-7235.

Table 1 shows the results of the evaluations of the two analog reference models (A, B) and the two conceptual proposals (C, D):

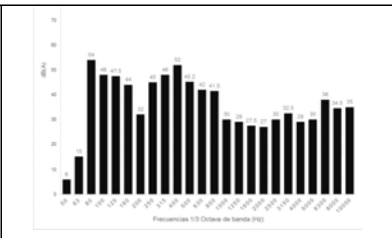
	Background Noise Level	Noise Source Level	Five points Average Level	Insertion Loss	Initial Wind Velocity	Measure Point Wind Velocity	Inner Ambient Temp
Model	N (dBA)	N_0 (dBA)	N_f (dBA)	(dBA)	W_0 (m/s)	W_f (m/s)	Temp °C
A	41.9	61.7	51.08	10.62	4	0.8	20
B	41.9	61.7	53.04	8.66	4	1.4	20
C	41.9	61.7	57.26	4.44	4	2.0	20
D	41.9	61.7	50.84	10.86	4	1.5	20

Table 1. Results of the analysis in the experimental element (Realized by the authors).

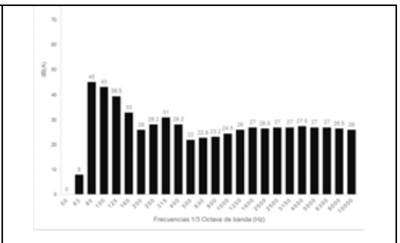
The graphs were made in Microsoft Excel program according to the format of the standard. The data recorded by the Omnimic V2 program of the frequency spectrum were captured manually (Figure 7).



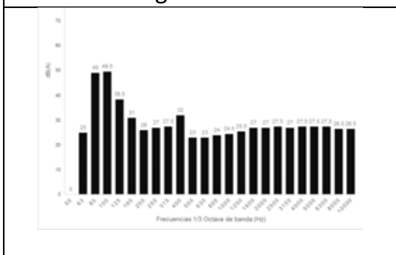
Background noise



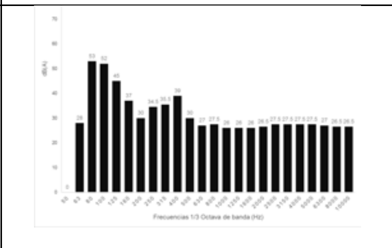
Reference noise



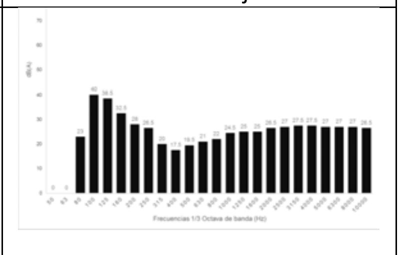
Reference Object A



Reference Object B



Proposal Design C



Proposal Design D

Figure 7. Comparative charts of results (Realized by the authors).

Conclusions

One of the contributions of the research is the development of an Experimental Instrument for the design and low-cost evaluation of different configurations of materials and geometries. This allows to modify and find better performances in terms of sound attenuation and airflow of natural ventilation devices of this type.

As an advantage, ISO 7235 allows the dimensions of the measuring instrument to be adapted according to the dimensions (area) of the ventilation devices. The insulation of ambient noise within the device is not a representative factor if a noise source with a level of at least 10 dB higher than the background noise level is used. To have accurate levels, the design was considered with acoustic insulation materials. Samples were also taken when there were no unexpected sources of noise affecting the average levels (airplanes, motorcycles, barking dogs).

The evaluated proposals are the result of the first design hypotheses. Some conceptual solutions were used as references for a state-of-the-art investigation of patents and commercial products (Ando et al, 2016). Alternative materials were proposed that can function because they have the characteristics of architectural application and has easy acquisition in any locality by its commercial use.

In the results of this experiment, one of the proposals could improve the performance of the reference models by attenuating some frequencies and airflow, although the performance in the insertion loss was similar. As future research, more designs will be proposed with other materials, alternatives and dimensions that can be adjusted to specific bioclimatic needs.

Finally, the experimental element will be able to design and evaluate a great diversity of proposals with a technological and educational purpose.

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Design to Thrive

Acoustic intervention proposal at the reception hall of the Children´s Hospital of Brasilia

Alexandre Guimarães[1], Elisa Naud[2], Jhennyfer Pires[3], Pedro Muza[4], Rosana Clímaco[4].

[1]AG Audio and Acoustic.Brasília, Brazil. contato@alexandreaudio.com.br;
[2]University Center of Brasília. Brasília, Brazil.Architecture and Urban Planning Department. Campus Asa Norte. arquitetura@uniceub.br;
[3]Euro Americano University Center. Brasília, Brazil. Architecture and Urban Planning Department. Campus ÁguasClaras. ana.costa@unieuro.com.br;
[4]University of Brasília. Brasília, Brazil. Faculty of Architecture and Urban Planning. Laboratory of Environmental Control and Energy Efficiency (LACAM). rosanasclimaco@gmail.com

The Children´s Hospital José de Alencar is an institution located in Brasilia, Federal District, and is dedicated to the care and treatment of children with cancer. The hospital physical space is divided into wings with different functions, interconnected by a single reception hall. The hall presents problems for it is a noisy environment due to the various activities held there, the large flow of people and the building geometry. Thus, in order to improve its acoustic performance and hence the comfort of hospital patients, this study aims to investigate the cause of the problem in order to propose an architectural solution that is compatible with the environment and its demands. The research was carried out in 3 steps: Diagnosis, evaluation of the hall problems and an architectural intervention proposal. The first step was to execute an in loco research and acoustic measurements. Then, from the collected data, a computational analysis of the space followed. The simulations and results were obtained through the computer software Ease v 4.4.11.4, Sound Forge Audio Studio 10 and Smart Acoustic Tools Analysis. Thus, the results pointed out that the environmental reverberation time was not satisfying according to the acoustic standard patterns, which caused great discomfort to users. In order to improve the environmental conditions, the intervention project took into account the infant theme, the hospital guidelines and the adjustment of the existing layout.

Keywords: Acoustic, Architecture, Hospital, Child, Passive energy.

Introduction

The José de Alencar Children’s Hospital (HCB), located in Asa Norte, Brasilia/DF, a centre specializing in integrated and multi-professional treatment, was designed by the architects Frederico Luís Carvalho and Sérgio Paulo Reis and was created by the initiative of the Brazilian Association for the Assistance of Families of Children with Cancer and Homeopathies. The HCB has adequate infrastructure, health technology and continuously trained staff. There is a large module with an entrance hall in Building 1, which is also a waiting room for patients, their companions and caregivers. In order to provide some comfort and distraction during the waiting time, the HCB offers some recreational equipment for children in this room. In addition, there is an entertainment, musical and theatrical program, as well as lectures, talks and other communication for them. Naturally, a large space with a considerable amount of people on the move generates a great deal of noise. The peculiar geometry of the space also contributes to the increase sound intensity. See Fig.1.

Figure 1. Photos of external and internal views of the entrance hall of Building 1

In Brasilia, the architect João Filgueiras Lima, also known as Lelé, innovated the conception of healthcare spaces. In other words, he revolutionized virtually all aspects of construction, infrastructure, facilities, equipment, environmental comfort, energy efficiency. Engineering and architecture are integrated in harmony. Lelé’s work is considered a point of reference for architectural solutions as a way of humanizing a hospital environment. One of his internationally recognized works became a model hospital network, called Sarah Kubitscheck, which was installed in a several cities in Brazil. He worked in partnership with the artist Athos Bulcão, creating environments where light, colours and joy fill the space. The latter’s works of art do not appear as an adornment of the surroundings. His art fulfils a functional purpose, such as environmental comfort or energy saving, as Segawa and Guimarães (2010) stated. See figure 2.

Figure 2. Photos of an internal corridor and external view the Hospital Sara do Lago Norte, Brasília.

In order to improve the acoustic surroundings in the aforementioned hall, a team of students and hospital staff got together to begin the project. Because it is a hospital environment focused on childcare, one of the project’s premises was to humanize this environment with a playful proposal. Thus, it is expected that waiting conditions will be improved, increasing users’ comfort. Another important point that drove the project was the search for a solution with the lowest possible energy and environmental impact, using alternatives with low implementation costs and taking advantage of the existing structure to improve the acoustic performance of this receptionhall.

Humanization of the hospital environment

The ambience of a hospital is often hampered by numerous guidelines because high-tech equipment and thorough sanitization processes are indispensable in such a place. In this regard, hospital models tend to follow a pattern far from being personalized and compatible with the expectations of those who work and are assisted there. The new Brazilian National Health Policy on humanization of hospital spaces (2006) states that welcoming and harmonious environments should be built in order to contribute to the promotion of well-being, thus unravelling the belief that such spaces provide health services in a cold and hostile way. This Policy also states noise treatment as one if the main concerns on improving comfort in hospital environments. A correct sound ambience can provide greaterwell-being, prolongs the length of stay in the room and promotes a sense of privacy in the space.

Ampt, Harris and Maxwell (2008) indicate in their studies that an environment with good acoustics can improve patient comfort, providing more privacy. It helps improve well-being by providing better rest conditions. It also improves physician and employee performances, helping their efficiency at work.

Project development

HCB Building 1 has an arched ceiling with reflective concavity, resulting unfavourable sound convergence. The height of the ceiling results in a very high volume- per-person ratio, which is also unfavourable to speech indexes; all the interior surfaces and walls reflect the sound. The furniture includes a few more sound absorbing items and the recreational equipment for children blends with the furniture in a confused layout. These architectural features of shape, material composition, occupation and layout are presented as issues to be focused in order to improve the acoustic performance of the hall. However, any intervention to be proposed should not change the architectural characteristics or the recreational ambience created, nor can discard furnitureitems.

Sound measurements

The objective of this step was to analyze and evaluate the acoustic conditions of the space through software simulation. For that, emission of sounds and measurements took place in loco according to the Brazilian Association of Technical Standards (ABNT), *NBR 10151*-proceddings (2003). The main focus was to analyze the Reverberation Time (RT) and the Sound Transmission Index (STI). The measurements had been made at night to avoid user´s noise at two points for sound emission possibilities: point1 (corner) and point2 (centre); the microphone were located at points A, B and C (see figures 3, 4). For the measurements had been used one PC, pink noise generated by Smaart Live 5 (Sound Forge Audio Studio10) emitted by a dodecahedral loud speaker and the microphone was the Behringer EMC8000. These measurements plus a 3D modeling of Building 1 were the inputs for the software program Ease v.4.4.11.4. Other complementary programs used: Sketchup v.5 and Smaart Acoustic ToolsAnalysis.

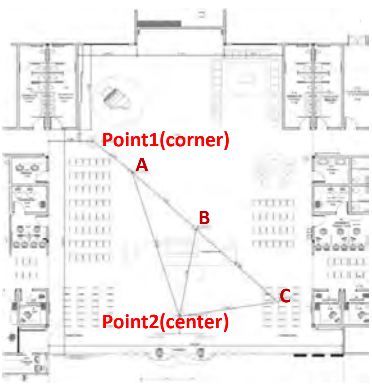


Figure 3. Plano f the entrance hall of Building 1: the sources and microphones measurements points

Figure 4. Panoramic view of the entrance hall of Building 1, with the central point of measurement

The acoustic evaluation parameters established were Reverberation Time (RT) and Speech Transmission Index (STI)

Multiple acoustical use spaces, if not designed for that, will need very criterions adaptations that should come from very precise diagnosis. In the case of a primordial use, the improvement design must focus on this objective, but IF the multiple functions are equally important, even contradictory in sound performance needs, high technology must be applied, which will be certainly more expensive.

In this case, the use adjustment of the space for speech can compromise its use for music. But the entertainment shows do not need very precise performance. Also is very important, in this space, to low the background noise level. The evaluation of the sound environment was based on acoustical standards concerning to the Reverberation Time (RT) and Speech Transmission Index (STI). The Brazilian standard for the RT by ABNT is NBR 12179 (1992. The STI indicate the comprehension of information transmitted orally; takes into account the reverberation time and noise of the rooms. “The STI indicates the correlation of the reverberation effect with background noise.” (Bertoli, 2008, apud Silva de Marco, 2009). In this case, the audience will not be in closed place, them the background noise will interfere very much in the speech, the primordial use of the space. The parameters for the STI evaluation in Brazil are established by IEC 60268-16 (2011); it consists of an index from 0 to 1, poor to excellent intelligibility.

Results and Evaluation

The values were obtained through the outputs of the mentioned Ease software in the form of tables and graphs. Here we reproduce the graph where the results are seen for the two measurement points, corner and center of the room as shown in Fig.3. The results are mean values of the various measurements made; also are shown the references values.

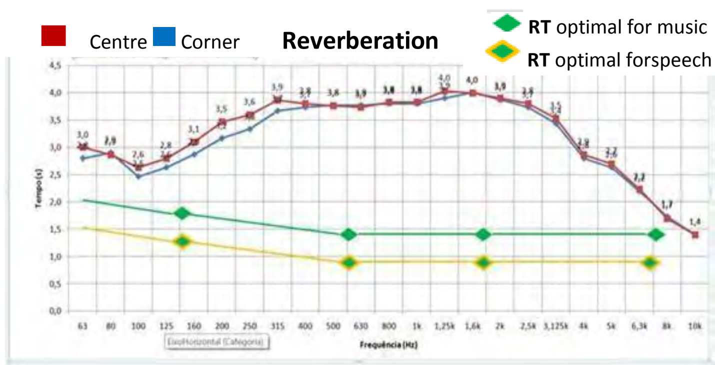
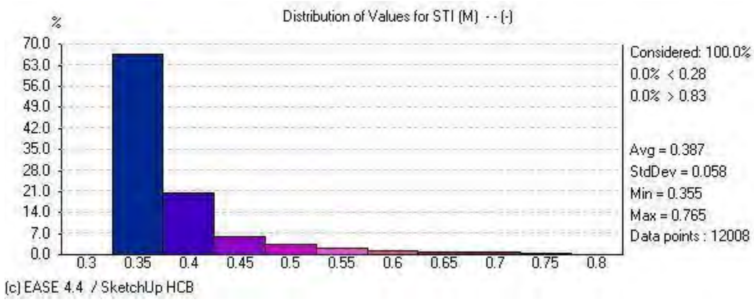


Chart 1 – RT Mean results for the two points (corner and centre of the room)

Reference values of RT(s) of NBR 12179, for the volume of 4,463 m^3, were considered for speech (conference room) in the frequency of 500Hz; the optimal values are 9s. The values obtained were 3.8s; the RT values for music are approximately 1.4 s, still far below those obtained (see Chart 1). For frequencies below 500Hz had been used the correction graph recommended by Silva de Marco (2003). A variation of 10% for more or less of RT as a result for an acoustic conditioning of a space, is considered acceptable. However, in all frequencies below 8kHz the values exceed by more than 200% the optimal values. TR values much higher than those recommended by the standard mean difficulty on understanding speech and increase the total sound intensity in the environment, thus increasing the background noise level. Another aspect to emphasize is that in the two measured places (corner and center of the room) the results were very close indicating the uniform distribution of the RT in the space.

The STI results, also obtained from simulations with the Ease program, show good values (0.75 to 0.57) only very close to the sources. The values already reach weak, 0.39 (see Chart 2) for points slightly more distant, approximately 6,0m. Lower values at increasing distance; it indicates speech intelligibility compromised within the space. Again, naturally, in both positions of the source, the results of the STI simulations were very similar as a result of the uniformity of the RT. (See Chart 2.)

Chart 2 – STI results of the simulations at the corner and at the center of the hall



Conclusions and intervention proposals

The main problems diagnosed for impairing the room acoustic performance are:
1. Large internal volume, which hinders the volume-per-person ratio for speech performance;
2. Its inner walls and other surfaces are very soundreflective;
3. The layout is unfavourable to assembling an audience;
4. Reverberation time results far beyond the Brazilian guidelinerecommendations;
5. Values of Speech Transmission Index are lower than standardreference.

Then, is conclusion of this study is that, this space can be adapted to its acoustic uses with good results, maintaining the original architecture and recreational environment with an very simple acoustic conditioning proposal. These aspects will be clear with the technical and aesthetic solutions chosen. According to the ''Health facilities humanization: design guidelines supported by statistical evidence'', a hospital waiting hall should prioritize spatial dynamics and the interactivity with the space. One should consider different types of need for privacy and socialization. In this sense, priority should be given to spaces that provide different ambience opportunities, always taking mutability into account. Therefore, to the proposal aims to boost the layout of the hospital furniture, creating audience venues for small performances, some reserved spots, and a space for games and music. See figure 5.

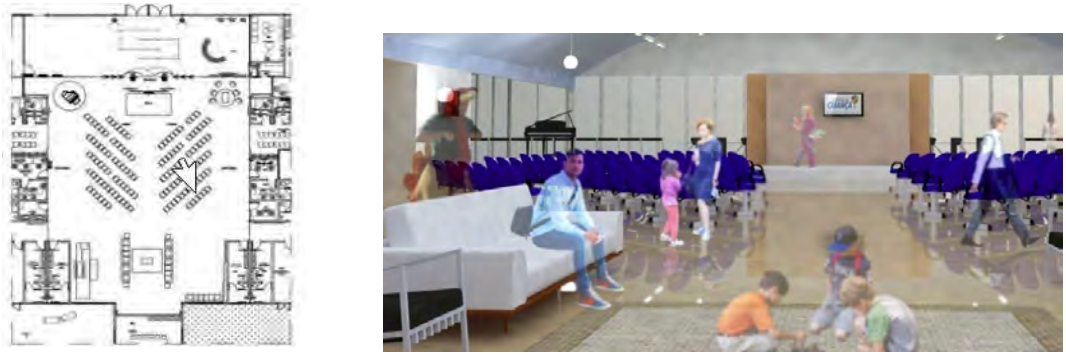


Figure 5. Layout proposal for the hall em plant and 3D image

Technical justifications for the proposals for adjusting Reverberation Time (RT)

As the results showed, a serious problem was the excessive Reverberation Time in basically all frequencies and its even distribution in the room. In order to reduce RT values and interfere as little as possible in the architecture and hygiene guidelines for hospital environments, we opted for the application of absorbent material throughout the ceiling surface. A sound-absorbing material made from PET wool was then specified, a product that uses recycling resources in the production of acoustic blankets, which satisfactorily replaces the use of rock and glass wool. We also proposed that the ceiling be printed azure with some clouds drawn onit.

Further simulations were made in the same programs with the new coating and the resulting values of Reverberation Times, now suitable; the values obtained are in the range of 0.44 to 1.83s from 100 to 10kHz; For 500Hz the value of TR is 0.75s; See Charts 3 and4.

Chart 3. RT Results at the corner

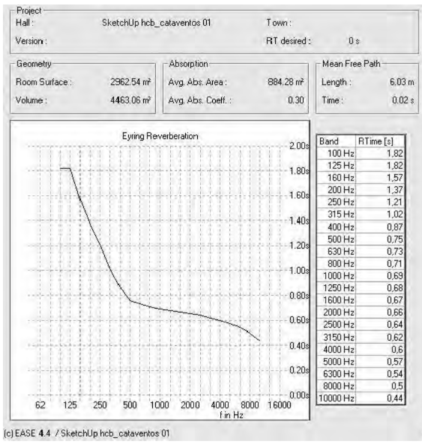
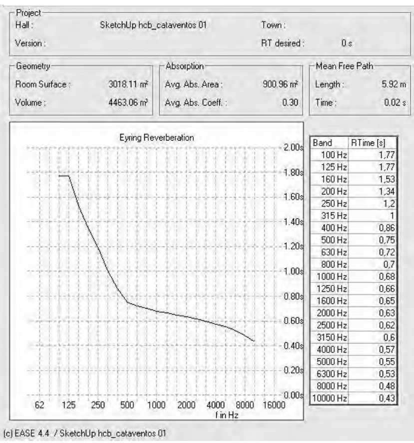


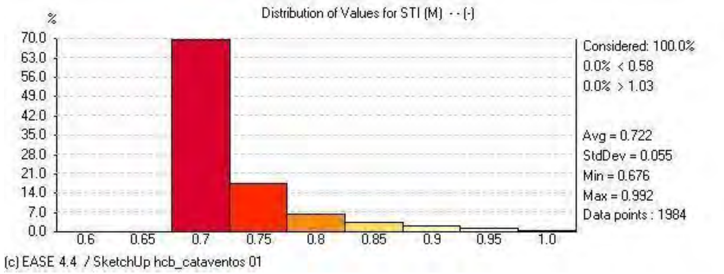
Chart 4. RT Results at the center of the room



Technical justifications for the proposed adjustments of Speech Transmission index

The simulation result values for STI taking the new materials in account also resulted in very significant improvements: the lowest values were 0.68. In spots furthest from the source, the results were considered good and the results in intermediate conditions were considered excellent. These data indicate very good speech audibility too. See Chart 5.

Chart 5. STI Results of simulations of the proposals for the corner and center of the space
From software *Ease v4.4.11.4*, 2016



Proposals for inclusion of sound reflection directing elements

The first is that the surrounding space must absorb the sound well; another condition is that the background noise must not be superior to the sound to be heard on-stage and the third is that the main source, that is, the sound source to be heard, must be directed to the audience; the emitted energy must be reflected to determined points through the inclusion of sound reflection elements. These should be directed to the most distant points of the audience, to avoid reflection to the closest listeners and the production of echoes. This reduces the intensity of sound, also improves the STI values and the perception of music.

The proposal consists of suspended elements in a windmill shape, similar to the hospital logo, made of MDF material or any other material with similar sound reflection coefficients, hanging above the light fixture, also suspended in the ceiling. It is important to note that they must be installed with precise inclination for a correct orientation of the reflections. The plan below shows the application schematics and 3D drawings illustrate for better visualization, figure 7:

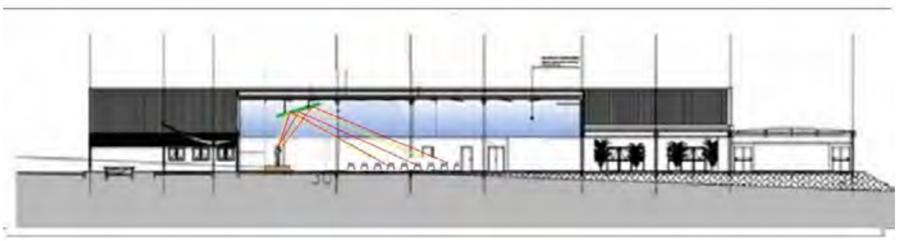


Figure 7- Illustration of the hall with the windmill and the related reflections for the audience

Figure 8 – Illustrations in 3D of the two proposal alternatives of the windmill implementations: eight smaller or three, bigger. Applied with defined inclinations.

Aesthetic justification of the proposal and conclusions

As mentioned, the application of these elements fulfills the function of directing the reflections of the sound rays. A technical function, not only decorative elements, but the aesthetical harmonization in the broadest sense of the term. There was also concern about the junction with luminaires that could not be removed. However, in addition to the two alternatives of colored varnishes, larger or smaller, were also presented the option of the same elements, colorless, transparent, made of acrylic or similar material, as "lighter" option, but of the same technical performance. See figure 8 above.

All conditions that initially seemed unfavorable and even incompatible with the acoustic use of that space, when analyzed and evaluated more judiciously, proved to fit the adequate expected result. The proposal was accepted by the team of HCB designers, and goes on to the executive design phase, adapting to the existing structure and enabling a new stage of studies on itseffectiveness.

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Design to Thrive

Workplace acoustic: A new perspective on noise dissatisfaction in open-plan spaces

Farrah Jahangeer[1]

[1] Ecole Nationale Supérieure d'Architecture de Nantes-Mauritius, Laboratoire AAU CRENAU, correspondence e-mail: farrah.jahangeer1@nantes.archi.fr

Abstract: Noise dissatisfaction in workplaces is a longstanding issue and open-plan layouts are commonly associated to this. The ability to represent the soundscape visually is explored here with the use of a new variable termed 'noise geometry' which is generated by the location of perceived noise sources when present in workspaces. Geometric indicators are used to quantify workspace geometry and noise geometry. The aim of this study is to develop this visual index so that it can be applied to early designs and is part of a doctoral study. It is hypothesised that a positive correlation exists between geometric indicators of workspace geometry and those of noise geometry is in turn negatively associated with acoustic satisfaction. Three sub-categories of open-plan spaces based on occupancies are investigated in a cross-sectional field study based in Glasgow: OP1 (< 10 employees), OP2 (between 10 and 25) and OP3 (> 25 employees) with a total of 153 open-plan spaces surveyed. The study also makes use of self-completed questionnaires and acoustic measures. The findings indicated significant associations between workspace geometry, noise geometry and acoustic satisfaction in two office categories. The possibility of visually indicating some aspects of noise perception is further discussed in this paper.

Keywords: noise, open-plan, acoustic satisfaction, geometry, spatial parameters

Introduction

Different aspects of noise in workspaces have been extensively investigated in the past with the aim of improving acoustic comfort and work performance; sources of office background noise (Danielsson & Bodin 2009), intensity of background noise (Landström et al. 1995; Seddigh et al. 2015) and speech transmission index (Haka et al. 2009; Loewen & Suedfeld 1992). Background conversations remain a pervasive issue in the workplace. The association between background conversations and noise dissatisfaction is further supported by the changing state theory of Jones et al. (1992) stating that uncontrollable and intermittent speeches are more annoying that constant loud noise. It could be argued that most studies investigating noise in the workspace are within acoustic or psychological fields and only several in the architectural field. Within the latter field, few studies have looked at open-plan layouts (Brennan et al. 2002) , individual workspace area and spatial density (Frontczak et al. 2012) in relation to employee noise dissatisfaction.

The geometry of workspace in relation to noise dissatisfaction is yet to be investigated. Recent studies investigated geometry of workspace and buildings in relation to building optimization for energy savings. Wang et al. (2006) looked at the variation in lengths and angles of a floor plan polygon in relation to building energy performance while Granadeiro et al. (2013) looked at the building envelope shape in relation to energy performance values of an existing building. However, the associations between workspace geometry, acoustic measures and employee dissatisfaction have not yet been analysed.

Alternately, the increased use of noise maps adds a two-dimensional aspect to urban acoustic analysis. Urban noise maps are used to analyse noise levels of a specific area in relation to the number of dwellings, inhabitants and the limits of noise exposure and the propagation of noise around buildings. However, this method assesses mostly noise intensities in relation to limit values within an area and is more revealing on a macroscale than a microscale. Alternately, sound maps, described by Schaffer (1977), indicate the types of noise sources and the perceived intensity of noise. It is considered that sound maps are more indicative of sound quality than noise maps. In this study, it is intended to develop a two-dimensional visual index derived from the use of geometry and sound maps that would be representative of noise dissatisfaction in open-plan workspaces. This 2-D visual index is also developed with the aim of providing an indicator of noise dissatisfaction at early design stages of open-plan workspace designs.

Definition of noise geometry

Studies making use of 2-D parameters when analysing the perception of noise in the workspace so far have made use of ego-centric distances (distance between listener and noise source) (Cabrera & Gilfillan 2002) and radius of distraction (radius within which STI is considered to be below 0.5)(Passero & Zannin 2012). Nonetheless, in these two aforementioned studies, the distance between sound source and listener are predetermined which is not the case in actual workspaces. A new two-dimensional visual index, termed as ‘noise geometry’, is introduced in this study and refers to the extent to which noise sources are discernible when one is momentarily present in a workspace. It is derived by placing convex envelopes around the location of identified (or perceived) noise sources when present in a workspace. Noise geometry is considered to be representative of an individual’s noise perception in relation to acoustic quality present and to the intensity of noise sources. Noise geometry is analysed in this study in relation to workspace geometry, acoustic measures and noise dissatisfaction.

Research questions and hypotheses

It is anticipated that the floor plan geometries are related to noise geometries which in turn are associated with employee noise dissatisfaction. In this study, the following research questions are being addressed: A) is open-plan floor geometry related to noise geometry? B) Is noise geometry associated to acoustic indicators? C) Is noise geometry related to noise dissatisfaction? Two acoustic indicators being studied here are reverberation time and background sound levels. Both studies of Perham & al. (2007) and Beaman & Holt (2007) indicated that the distance between noise source and listener is related to reverberation time. Here we look at reverberation time of different workspaces in relation to the noise sources perceived and to noise geometry. For question A it is hypothesised that at least one of the indicators would indicate a positive correlation between open-plan floor geometry and that of noise geometry. The same type of correlation is expected for noise dissatisfaction variables in question C. However, for question B it is expected that the increase in at least one indicator of noise geometry would be associated with an increase in noise level but a decrease in reverberation time. The expected negative correlation between reverberation time and noise geometry are based on the results of Perham et al.

(2007) and Beaman & Holt (2007) where noise sources were more discernible when reverberation time decreased.

Research methodology

Research Sample

The study was based in commercial areas of Glasgow City centre. The workspaces of participating organisations were situated in multi-storey buildings mostly built before 1950s. Interior of workspaces had been refurbished within the last 10 years and had carpet flooring and plasterboard walls. Ceiling finishes (suspended metallic or cork acoustic panels) and the size of openings varied among the workspaces. Participating organisations were divided into three open-plan categories based on occupancy: OP1 (less than 10 employees), OP2 (between 10 and 25 employees) and OP3 (more than 25 employees). The sample consisted of a total of 153 participants with 33 in OP1, 34 in OP2 and 86 in OP3. The percentage of females in the sample were: 79% in OP1, 64% in OP2 and 38% in OP3. The median age group in OP1 was 30-39 years and in OP2 and 40-49 years in OP3.

Research design and procedures

A cross-sectional research design framework was applied to this study with the use of both subjective and objective measures. Self-completed questionnaires were used to evaluate satisfaction levels of employees on a 5-point Likert-type scale for acoustic satisfaction and work performance satisfaction. Questions for acoustic satisfaction evaluated background office noise, communication level, frequency of raising voice during a conversation and frequency of overhearing background conversations. For work performance, employees were asked to rate the frequency of difficulty faced when completing tasks, the ability to remain concentrated, frequency of distraction caused by background conversations and preference to work in a cellular workspace. Participants were also asked to identify the most annoying noise source in the workplace. Participation in the survey was voluntary and completed paper questionnaires were collected at the end of survey period.

For objective measures sound levels, workspace dimensions, type of desk layout (linear or non-linear) and location of noise sources when present in workspace were recorded in each workspace. Sound level was measured over a period of 7 hours with a calibrated sound level meter (CEM DT-8851/8852) and reverberation time was calculated using Sabine's formula $R = \frac{0.16V}{A}$ (Furrer 1964), where *R* is reverberation time, *V* is volume and *A* is total absorption surface areas. Besides acoustic and workspace measures, two shape descriptors applied to the field of Geometric Information Systems were used to quantify geometry: area and elongation ratio. Area represented the size of the geometry while elongation ratio described the form of the geometry. Elongation ratio was calculated by using Dauwalter & Rahel's (2011) method - $A/_{L^2}$, where *A* is the area of geometry and *L* is the maximum length of geometry. The values for the later vary between 0 and 1 where 0 indicates a stretched rectangle and 1 represents a perfect square. A bounding box was placed around the geometry using Toussaint's (Chan & Tan 2001) 'rotating calliper' technique and from which the maximum lengths and widths of the geometry were derived.

Data analyses

The intention of the study was to determine the nature of the relationship, if any, between workspace floor geometry, noise geometry, acoustic measures and satisfaction ratings. For the analysis of geometry indicators, areas of noise geometry were correlated with those of workspace floor geometry but not with elongation ratio values because area and elongation are two different indicative aspects of geometry and are not necessarily associated. Questionnaire answers were coded from 1 to 5 with 5 being the most positive response and each participant in the survey was considered as a case. The sample size was considered to be moderate and with a non-normal distribution. SPSS version 21 was used here for all data analyses. Kruskal-Wallis test was used to indicate significant differences among the three workspace types for objective variables. Median absolute deviation was used here and values out-with 2 absolute deviations from median were considered outliers for 95% confidence interval. Spearman's Rho test was used for bivariate analyses and *p-value* under 0.05 indicated strong associations between variables.

Results

People talking was the most annoying noise source in all three open-plan categories (see Figure 1 below). Percentage of employees satisfied with acoustic background in general was as follows in the three categories: OP1 – 59.1%, OP2- 36.8% and OP3 – 41.3%. In all three types of workspaces percentage of employees reported being distracted by background conversations were above 50%. Kruskal Wallis test indicated significant differences among the three office types for noise level ($X^2(2) = 34.9$, $p<0.05$) and reverberation time ($X^2(2) = 25.4$, $p<0.05$) highlighting that both noise level and reverberation time tended to increase from OP1 to OP3. The median noise level for each category were as follows indicating an increase in noise level with the occupancy; OP1=45.4 dBA, OP2= 48.9 dBA, OP3= 52.0 dBA. Median reverberation time for each category was as follows; OP1 = 0.40s, OP2= 0.88s and 1.14s. Geometry indicators also differed significantly among the three categories; workspace floor area ($X^2(2) = 108.9$, $p<0.05$), noise geometry area ($X^2(2) = 120.6$, $p<0.05$), elongation of workspace floor ($X^2(2) = 41.5$, $p<0.05$) and elongation of noise geometry ($X^2(2) = 114.3$, $p<0.05$).

Workspace geometry and noise geometry

The results obtained in OP1 and OP2 supported the hypothesis stating that one of the geometry indicators would show a positive association between workspace geometry and noise geometry. In OP1 workspaces, area of floor geometry and that of noise geometry increased together ($r=0.681$, $N=33$, $p<0.01$) and the elongation of noise geometry increased together with that of floor geometry ($r=0.684$, $N=33$, $p<0.01$). The increase in floor areas of OP1 workspaces above the median of 57.5m^2 had linear desks arrangements and noise geometry area above the median value of 16.0m^2 thereby suggesting that employees in larger OP1 workspaces were within closer proximities (employees were closer to each other in linear desk arrangements than those in non-linear desk layouts) and hence conversations were more likely to be heard. In OP2 workspaces, the increase in floor area above 98.6 m^2 was also associated with an increase in area of noise geometry ($r=0.664$, $N=34$, $p<0.01$) above 31.2 m^2 but no significant correlations were observed for elongation values between workspace floor geometry and that of noise geometry. The association between floor geometry and type of desk arrangement was irrelevant in OP2 workspaces because all offices had linear desk layouts. Geometry indicators showed no significant correlations between floor geometry and noise geometry in OP3 spaces. Associations between workspace geometry indicators, noise geometry indicators and desk layout were not coherent in OP3 offices and this was considered to be partly related to the fact that one workspace in the sample had a different design feature – part of the office walls were not full-height thereby producing incoherent results.

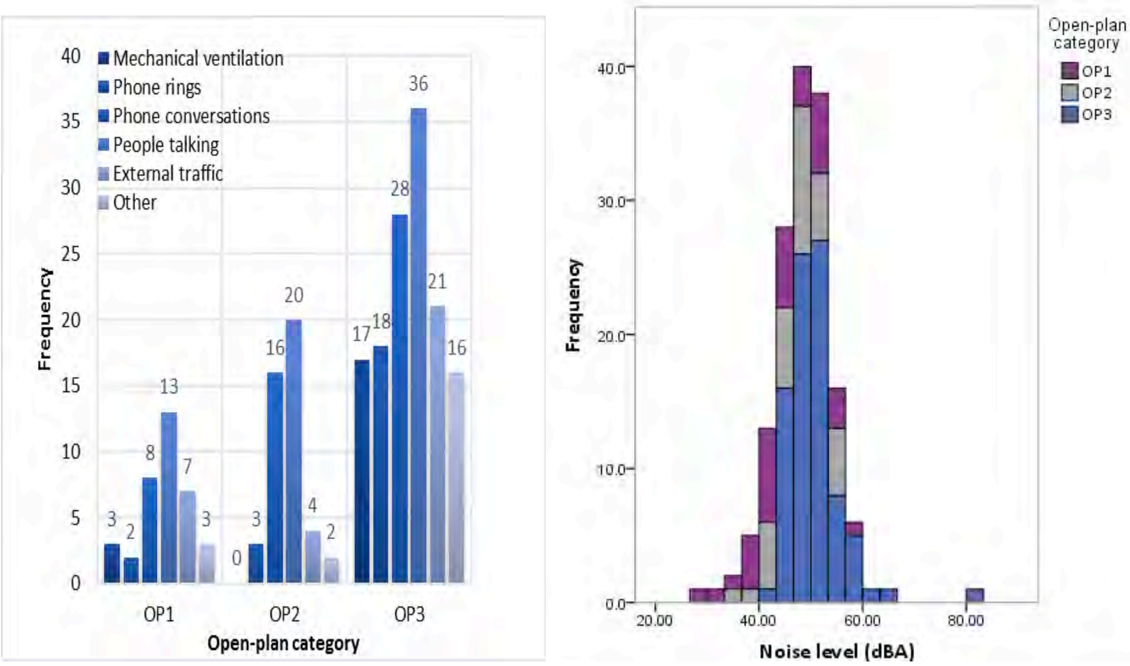

Figure 1. Graphs indicating most annoying noise sources in each office type

Noise geometry and acoustic measures

As seen in Table 1, the associations between workspace geometry indicators and acoustic measures varied according to office category thereby failing to support the expectation that the increase in floor area would likely be associated to an increase in both noise level (because of the increase in occupancy) and an increase in reverberation time (because of an increase in volume). The findings indicated that in OP1 workspaces, the increase in area of noise geometry above $16m^2$ was associated with an increase in noise level (see Table 1.0) above 44.4 dBA. No significant association was observed between area of noise geometry and reverberation time in OP1 but elongation value of noise geometry in OP1 was positively associated with both noise level and reverberation time. In OP2 workspaces, an increase in both area above 31.2 m^2 and elongation ratio value above 0.31 of noise geometry was associated with a decrease in reverberation time below 0.95s. No significant correlations were observed between noise geometry indicators and noise level in OP2. In OP3 workspaces, the increase in both noise geometry area above 76.6 m^2 and noise geometry elongation ratio above 0.69 was associated with a decrease noise level below 52 dBA. No further significant correlations were observed between noise geometry indicators and reverberation time in OP3 spaces. The hypothesis stating that the increase in at least one indicator of noise geometry would be associated with an increase in noise level but a decrease in reverberation time was not supported in any of the three workspace categories.

Table 1. Spearman's Rho correlation coefficients when analysing geometries and acoustic measures in each workspace type. Significant where ** p<0.01, * p<0.05

	Reverberation time			Noise level		
	OP1	OP2	OP3	OP1	OP2	OP3
Workspace geometry area	0.545**	-0.664**	-0.877**	0.493**	0.060	0.353**
Workspace geometry elongation	0.025	-0.664**	1.000**	0.334	0.060	-0.603**
Noise geometry area	0.096	-1.000**	0.048	0.607**	-0.099	-0.455**
Noise geometry elongation	0.378*	-0.569**	0.048	0.447**	-0.195	-0.455**

Noise geometry and noise dissatisfaction

The hypothesis stating that at least one indicator of noise geometry would be positively associated with noise dissatisfaction was supported in all three workspace types (see Figure 2). In OP1 workspaces, the increase in area of noise geometry above 16 m^2 was associated with a decrease in acoustic background satisfaction (r=-0.377, N=33, p<0.05) from 75% to 47.4% (see Figure 3.) and an increase from 53.6% to 29 % in the preference to work in a cellular office (r=0.511, N=33, p<0.01). No significant correlations were observed between elongation ratio values and acoustic satisfaction ratings or work performance ratings in OP1 workspaces. In OP2 workspaces, the increase in area of noise geometry above 31.2m^2 was significantly associated with a decrease in acoustic background satisfaction (r=-0.370, N=34, p<0.05) (see Figure 4.) from 60.8% to 29.2% and an increase in the preference to work in a cellular office (r=0.355, N=34, p<0.01). No significant correlations were observed between elongation values of noise geometry and employee satisfaction in OP2 spaces. In OP3 workspaces, it was also observed that the increase in noise geometry area above 76.6m^2 was associated with a decrease in acoustic background satisfaction (r=-0.317, N=86, p<0.01) from 80% to 35.5% and with an increasing preference to work in a cellular office (r=0.285, N=86, p<0.01). However, in OP3 spaces, elongation ratio values were significantly associated with acoustic background satisfaction (r=-0.317, N=86, p<0.01) and the frequency of perceived noise disturbances (r=0.507, N=86, p<0.01).

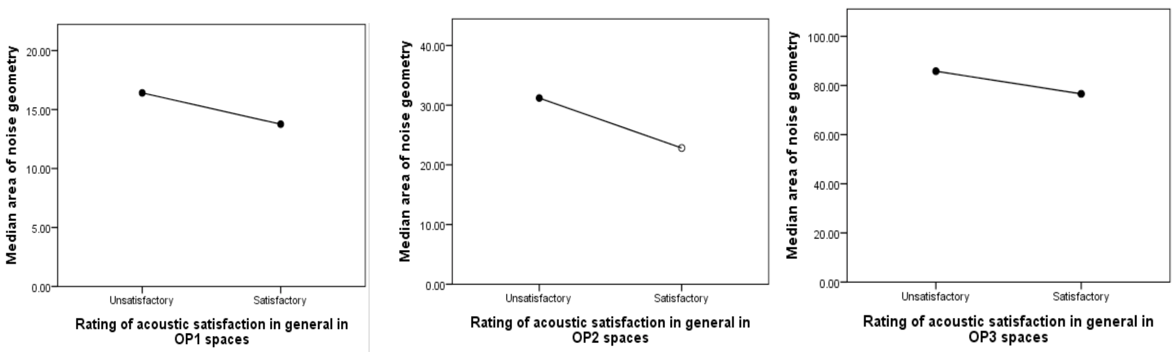

Figure 2. Acoustic satisfaction ratings in all three workspaces

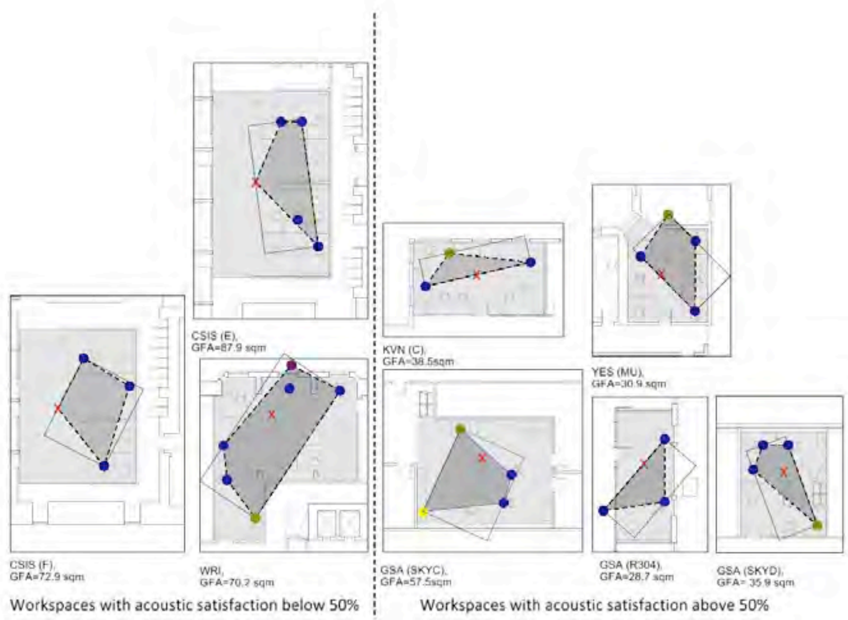

Figure 3. OP1 workspaces with associated noise geometries and acoustic satisfaction ratings

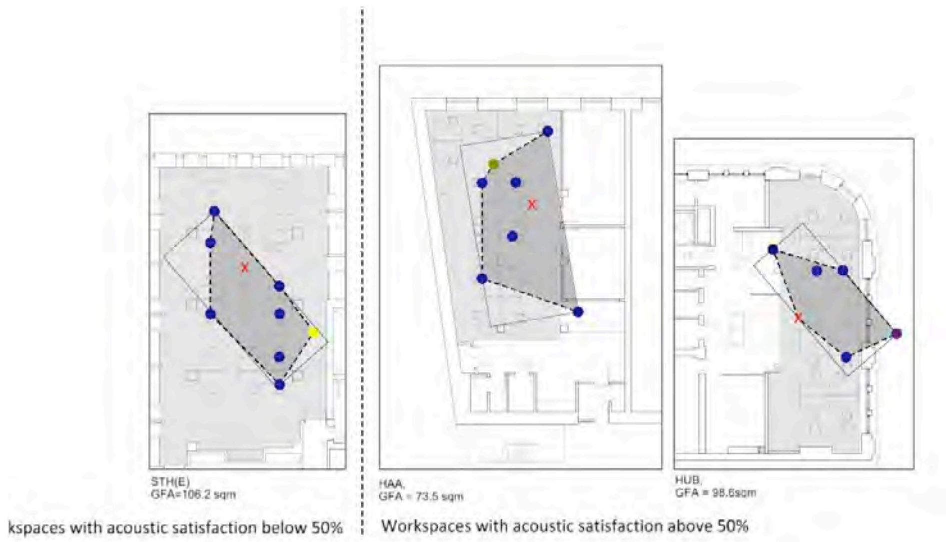

Figure 4. OP2 workspaces with associated noise geometries and acoustic satisfaction ratings

Discussion

The results supported the hypothesised positive correlation between noise geometry and acoustic satisfaction in three workspace categories which could be considered a starting point in the development of a visual index for acoustic satisfaction in the workplace. The associations between workspace variables were coherent only in OP1 and OP2 workspaces thereby indicating that workspace geometry, noise geometry and noise dissatisfaction are interrelated but not necessarily in the same way. In OP1 spaces, the increase in floor area was associated with an increase in noise geometry area and a dissatisfaction in acoustic satisfaction. In OP2 workspaces, the increase in floor area was associated with a decrease in reverberation time and a decrease in acoustic satisfaction. In OP3 spaces, it was considered that the uncommon architectural features, such as openings and gaps in partitions led to diverging and incoherent results. The negative correlation between noise geometry and reverberation time in OP2 space begins to question the common tendency of reducing reverberation in open-plan spaces. Only two GIS factors, area and elongation were analysed here and area was more significant than elongation ratio. Perhaps other GIS factors, such as Shape Index might be more relevant when quantifying the geometries. Future areas of investigation might focus on the variation of noise geometry with time in relation to acoustic satisfaction in the workplace with the possibility of determining a noise geometry pattern.

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The effect of environmental characteristics of cities on urban noise

Lucas Dellosso Penteado[1], Léa Cristina Lucas de Souza[2], Guillermo López[3]

[1] Civil Engineer, Master student in Urban Engineering Program, Federal University of São Carlos, São Carlos, Brazil, email penteado.lucas@gmail.com;
[2] Urban Engineering Program, Department of Civil Engineering, Exact and Technology Sciences Center, Federal University of São Carlos, São Carlos, Brazil, email leacrist@ufscar.br;
[3] Physical Engineer, Federal University of São Carlos, São Carlos, Brazil, email guillermo.angel@usp.br;

Abstract: The aim of this paper was to verify the influence of urban features on the patterns of surrounding sound pressure levels. In these study areas, 28 points were distributed into two routes located in São Carlos (Brazil). These points were taken as references to measure A-weighted equivalent sound pressure levels (L_{AEq}), as well as to determine the urban geometry parameters, such as the street height and width ratio (H/W factor), the volumetric index and the occupation rate. The results show that one of the areas presents a high correlation with the sound levels. Furthermore, among the factors studied, the building height, the volumetric index and the occupancy rate were highly important considering the increase of sound pressure levels.

Keywords: Environmental Noise, Urban acoustics, Urban Indices, Urban form indicators.

Introduction

Sound pollution interferes directly in inhabitants quality of life in urban centres, regardless of the size of the city. According to the World Health Organization (WHO, 2012), 10% of populations suffer from some type of disease caused by noise, such as hypertension, sleep disturbance and hearing loss. The European Union (EU) (Directive 2002/49/EC on the management of environmental noise) defines environmental noise as “unwanted or harmful outdoor sound created by human activities, including noise from roads, rail, airports and industrial sites”.

Even though road traffic noise is one of the main sources of urban noise, there is also a role played by urban forms considering the increase in sound levels. Sound can be absorbed, reflected or transmitted according to the characteristics of the urban geometry. In the urban environment, propagation of sound waves is affected by the existence of green areas, building heights, street widths, materials used on the façades and their absorption. The more impervious the urban mesh is, the greater the reflections causing the phenomenon of sound reverberation. Bistafa (2006) shows that various sound reflections on the facades of buildings may cause noise to amplify. Okada, Yoshihisa and Kuno (2010) observed an increase of 8dB related to the reflections of traffic noise on building facades. Guedes and Bertoli (2005) show that the influence of sound waves reflected on the urban environment can cause discomfort to some areas, and none to others.

Wang and Kang (2011) and Salomons and Pont (2012) emphasize that urban morphology (including the width of roads, squares, building heights bordering roads, green areas and urban densities) affects and potentializes sound propagation in urban centres. These authors have found a positive correlation between noise pollution and the higher density of cities. However, narrower roads, complex road networks and higher density of intersections lead to lower traffic volume, and thus, lower noise levels. Other studies have also found that various morphological elements in the urban environment can influence noise pollution, such as construction density, open spaces, as well as the shape and physical position of the buildings (Souza and Giunta, 2011; Oliveira and Silva, 2011).

This paper verifies the influence of urban features, such as street width and building height ratio, on the patterns of noise pressure levels encountered in urban areas. For this purpose, two pedestrian routes in a medium-sized Brazilian city were investigated.

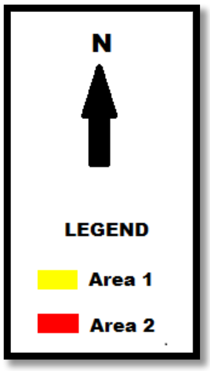
Methodology

The equivalent noise pressure levels (L_{AEq}) of two neighbourhoods in the city of São Carlos in São Paulo State, south Brazil were studied. This city is situated at 22° 01′ 03″ latitude and 47° 53′ 27″ longitude, and the average elevation is 854 m above sea level. São Carlos, located in the middle of São Paulo State, has an area of 1143.9 km^2 and a population of 221,950 (IBGE 2010) inhabitants.

The two study areas can be seen in Figures 1 and 2. The neighbourhood of Area 1 is a commercial zone and it is located in the city centre. The route that was studied connects the central area to Campus I at the University of São Paulo (USP). The second neighbourhood (Area 2) is a residential zone that resulted from new urban planning. Both routes begin in areas where there is a high concentration of services, as well as student and family residences and each one ends at one University Campus. Considering both areas, a total of 28 points were selected to determine the sound pressure level measurements: 11 points in Area 1 shown in Figure 3 and 17 points in Area 2 shown in Figure 4.

Figure 1. Studied Area 1.

Figure 2. Studied Area 2.



Data collection

First, the peak periods of vehicle traffic were identified. They are on regular weekdays from 7 a.m. to 8:00 a.m. and 5:30 p.m. to 7 p.m. Data was collected to determine the vehicle traffic at each one of the 28 reference points distributed along two routes, one for each area. In Area 1 there are 11 points along the route and in area 2 there are 17 points along the route. Figures 3 and 4 show these points and the routes. Weekends (including Fridays and Mondays) and holidays were excluded from the data collection.

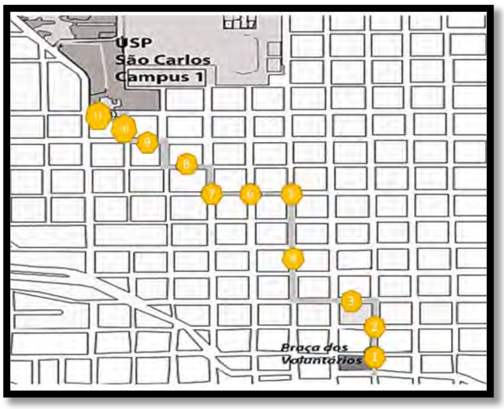


Figure 3. The eleven measurement points along the route in Area 1.

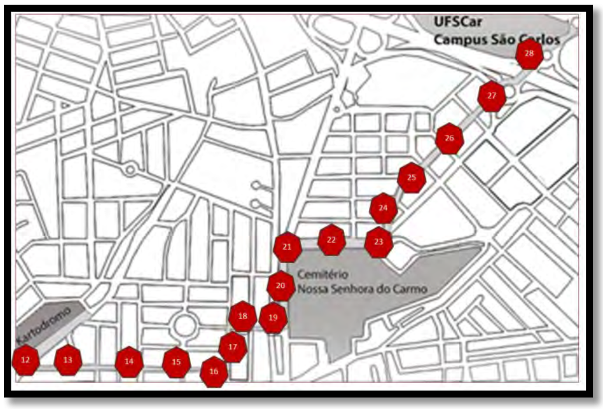


Figure 4. The seventeen measurement points along the route in Area 2.

Afterwards, characterization of the street noise was performed. Noise levels (L_{Aeq}) were registered at the same reference points for the two periods determined as peak periods. The L_{Aeq} values were obtained with the sound pressure meter Analyser 2270-L proposed by Brüel & Kjaer, which was set up to integrate levels at an A-weighted scale and in a fast response mode, over 5 min. The equipment was positioned at a height of 1.20 m from the ground, keeping a distance of at least 2 m from reflective surfaces (walls) and facing street traffic.

Afterwards, the urban features were determined. Cadastral maps of the study area were collected to identify the location of each building within the lot. The height of each of these buildings was then quantitatively estimated by visual site inspection. The estimation of the building heights had a local floor height standard of 4 m, which is generally adopted for the ceiling height of each building floor.

A statistical analysis was performed to study the influences of the Occupation Index (Construction area/Block area) and the Volumetric Index (Volumetric Index of the construction/Block area) on the sound pressure levels. These levels were also compared to the acoustic parameters established by the Brazilian technical standards NBR 10.151 (ABNT, 2000).

The sound values were compared to the geometric parameters and the urban indexes obtained for each block. For each point of measurement of the equivalent sound pressure level, the influence of the four adjacent blocks of the measurement point was analysed.

Results and Discussion

In order to verify the relation between the noise and urban geometry, in Fig. 5, the L_{Aeq} obtained in the 28 points are shown. It is noticeable that all values found are higher than the Brazilian NBR 10.151standards. As can be seen, both study areas have a high level of noise with a maximum level of 75.3 dB. According to NBR 10.151 for areas whose main use is residential, the maximum noise level allowed is 55 dB for the morning and evening, and 50 dB during the night.

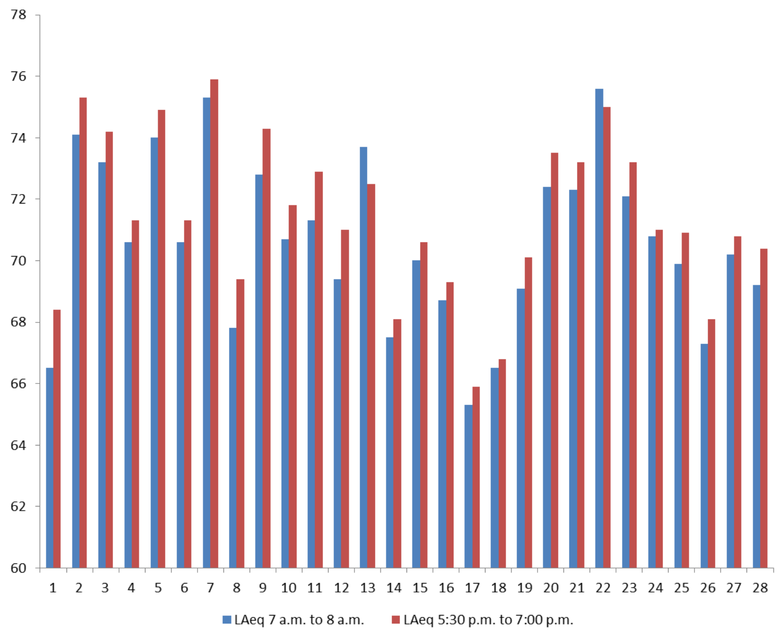


Figure 5. Measured values for each point in both periods

Therefore, both areas presented high levels of noise. When comparing them, as shown in Table 1, Area 1 (regular configuration) presents a higher noise level and a higher Occupation Index than Area 2 (irregular configuration).

Table 1. Values of sound pressure levels and landscape metrics.

	Sound pressure level			Occupation Index (%)	Volumetric index		
	Min	Max	Average		Min	Max	Average
Area 1	66.50	75.30	71.54	46%	0	3.52	1.59
Area 2	65.30	73.70	70.00	39%	0	2.88	1.48

As shown in Table 2, Area 1 shows a higher building height than Area 2, however the maximum H/W ratio (up to 2.0) occurs within both of them.

Table 2. Values of Urban features.

	Building height (m)			Street width			H/W		
	Min	Max	Average	Min	Max	Average	Min	Max	Average
Area 1	4.00	40.00	14.91	9.50	18.00	9.93	0.1	2.90	0.88
Area 2	4.00	30.00	10.64	7.50	18.00	11.24	0.1	2.43	0.53

In Table 3, the data collected in Area 1 are presented: sound pressure levels, road speed limit, street width, building height, occupancy index (Sum of built-up areas/Block area) and volumetric index (built volume / block area) and the H/W ratio. It can be observed that the highest noise indexes are related to high velocity indexes and to high H/W ratios, which always have values higher than 1.

The only point that does not respect the rule of this relation is point 11, where the sound pressure level is 71.30 dBA for the morning period and 72.90 dBA for the night period, and the H/W ratio is 0.40. This variation is probably due to the presence of traffic lights and bus stops.

Table 3. Data collected and analysed from Area 1.

Point	LAeq (dBA) - 7 a.m. to 8 a.m.	LAeq (dBA) - 5:30 p.m. to 7 p.m.	Speed limit (km/h)	Street width (m)	Building Height (m)	Occupation Index (%)	Volumetric Index	H/W
1	66.50	68.40	30.00	15.00	8.00	0.11	0.62	0.53
2	74.10	75.30	50.00	16.80	18.00	0.29	5.75	1.07
3	73.20	74.20	50.00	27.35	44.00	0.37	13.75	1.61
4	70.60	71.30	50.00	13.80	40.00	0.33	10.86	2.90
5	74.00	74.90	50.00	16.00	18.00	0.35	7.70	1.13
6	70.60	71.30	50.00	13.00	16.00	0.31	7.14	1.23
7	75.30	75.90	50.00	10.00	4.00	0.31	6.79	0.40
8	67.80	69.40	30.00	10.00	16.00	0.37	6.65	1.60
9	72.80	74.30	50.00	13.00	16.00	0.32	5.28	1.23
10	70.70	71.80	50.00	13.00	20.00	0.38	6.65	1.54
11	71.30	72.90	50.00	20.00	8.00	0.27	4.03	0.40

It can be seen that the higher the ratio of the volumetric index, the higher the sound levels obtained. Thus, the volumetric index of the neighbourhood as well as the H/W ratio are parameters, which are useful in predicting sound pressure levels.

Table 4. Data collected and analysed from Area 2

Point	LAeq (dBA) - 7 a.m. to 8 a.m.	LAeq (dBA) - 5:30 p.m. to 7 p.m.	Speed limit (km/h)	Street width (m)	Building Height (m)	Occupation Index (%)	Volumetric Index	H/W
12	69.40	71.00	50.00	13,00	16.00	0.18	1.80	1.23
13	73.70	72.50	50.00	11,50	28.00	0.22	2.89	2.43
14	67.50	68.10	50.00	14,80	12.00	0.30	4.49	0.81
15	70.00	70.60	30.00	14,15	4.00	0.32	6.62	0.28
16	68.70	69.30	30.00	14,50	8.00	0.30	6.25	0.55
17	65.30	65.90	30.00	14,00	4.00	0.26	4.67	0.29
18	66.50	66.80	30,00	9,85	10.00	0.26	4.67	1.02
19	69.10	70.10	50.00	10.00	4.00	0.32	2.20	0.40
20	72.40	73.50	50.00	48.50	3.00	0.03	1.80	0.06
21	72.30	73.20	50.00	46.00	8.00	0.03	1.80	0.17
22	75.60	75.00	50.00	18.00	800	0.15	2.89	0.44
23	72.10	73.20	30.00	55.60	4.00	0.13	3.95	0.07
24	70.80	71.00	30.00	14.35	4.00	0.31	5.16	0.28
25	69.90	70.90	50.00	14.85	4.00	0.31	5.16	0.27
26	67.30	68.10	50.00	86.45	30.00	0.31	6.87	0.35
27	70.20	70.80	50.00	92.00	30.00	-	-	0.33
28	69.20	70.40	50.00	169.00	4.00	-	-	0.02

Table 4 presents the data from study Area 2. In this region of study, a correlation between the sound pressure levels and the H/W and volumetric index could not be found. We believe that one reason for this behaviour is the recent occupation patterns of Area 2, when compared to Area 1. Area 2 presents larger numbers of empty urban spaces and less vertical constructions. Points 27 and 28 were disregarded in the analysis of the occupation index and volumetric index, because they were located near the access road to the Federal University of São Carlos, which represents a distinct noise source and land occupation.

In addition, in Area 2, the distribution of the blocks is more irregular, presenting a lack of standardization in the dimensions of the urban blocks, presenting larger urban voids as in the vicinity of points 12, 27 and 28, which are private properties with no buildings. Points 20 and 21, which are located in the vicinity of the municipal cemetery, have large areas but with little volumetric construction, thus not leading to a significant interference in the noise of the environment.

Conclusions

In the present research, the joint analysis of sound pressure levels and landscape features has shown to be a suitable and an efficient tool to describe their relationship. There is a clear positive correlation between the H/W ratio and the sound pressure levels, at least for Area 1. However, though being positive, this relationship is less important when considering Area 2 for which the configuration is irregular.

Both areas under analysis presented high levels of noise, reaching values not within the healthy levels suggested by the Brazilian technical standards. Further studies should focus on these points, if a sustainable environment is to be reached.

Acknowledgements

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Developing Sound Absorbers for Health Facilities. How to meet hygienic and acoustic Requirements in one Product

Dr. Uta Pottgiesser[1], Christoph Kirch[2]

[1] Henry van der Velde Research Group, Faculty of Design Sciences, University of Antwerp, Antwerp, Belgium, uta.pottgiesser@uantwerp.be;
[2] Detmold School of Architecture and Interior Architecture, Ostwestfalen-Lippe, University of Applied Sciences, Detmold, Germany, christoph.kirch@hs-owl.de

Abstract: The hygienic requirements in health facilities, in particular in hospitals, lead in most cases to hard and high reflective surface materials and subsequently to long reverberation times. The noise level is high and the resulting speech intelligibility is low – both indicating poor room acoustics with stress-increasing impacts. In contrast, good room acoustics will help staff members to work more concentrated and with less mistakes and patients will profit from a better prevention, regeneration and healing.
Sound absorbers generally reduce reverb and create a comfortable acoustic environment. Additionally, sound absorbers for health facilities and hospitals need to reach the hygienic requirements on cleaning and disinfecting surfaces. This means in general, that surfaces need to be non-porous and smooth to implement the hygienic requirements, however, porous materials like foams are regularly used for sound absorbers. The purpose of the project was to develop a sound absorber that can be disinfected easily and with material that is chemically resistive to the usual disinfecting products. Constructive and acoustical solutions were developed and evaluated to meet the requirements of a high effective sound absorber with an aesthetic non-technical appearance to be used in common patient rooms and for specific applications in health facilities.

Keywords: Product development, Sound Absorber, Health Facilities, Hygienic requirements

Introduction

The disinfection of surfaces in clinics and mass catering institutions not only serves the cleanliness, but also the personal protection or the protection of health to prevent infection. For this reason, rooms, machines, all installations and component surfaces (walls, ceilings, floors and in particular acoustic elements) must be cleaned and disinfected on a regular basis.
According to the “Requirements on Hygiene when Cleaning and Disinfecting Surfaces – Recommendations by the Commission for Hospital Hygiene and Infection Prevention of the Robert Koch Institute“ (RKI, 2004) the surfaces of installations (ceilings, doors, walls) must be as smooth as possible, wipeable, joint-tight and cleanable with disinfectants and disinfecting procedures. Porous materials, mostly used for sound absorbers, have neither a smooth, closed surface nor can they be easily disinfected and therefore do not meet the increased requirements of the hygiene sector.

As a rule, the hygiene requirements in medical facilities lead to reverberant building and finishing materials, and thus to unfavourable room acoustics. The long reverberation times lead to a noisy environment with a low speech intelligibility (DIN 18041, 2015). Thus communication and concentration is disturbed even at low noise levels, resulting in reduced performance and increased frequency of errors. Regeneration (sleep) and healing are already adversely affected with very low noise levels. Both aspects are of great importance especially for patients (regeneration) and personnel (concentration) in medical, nursing and care-taking facilities (Notbohm and Siegmann, 2012).

In the presented research, the development, layout and design of a porous sound absorber was carried out which is to allow reliable cleaning and disinfection measures for the use in rooms of the healthcare environment, such as clinics and nursing facilities, as well as kindergartens and associated kitchen areas.

Conception

Since a modular design and a high and broadband efficiency should be maintained, the system needs to be encased in order to prevent microorganisms from penetrating the porous absorber's core. This protective layer should also remain acoustically transparent over the entire frequency range relevant for room acoustics.

At the same time the mechanical robustness should be as high as possible for the daily clinic routine so that it is not damaged easily by scratches. The materials and surfaces must be selected in such a way that they are resistant to cleaning and disinfecting agents when applied in specific doses and cycles. Liquids or humidity should not penetrate the porous absorber's core since there are a variety of active substances and substance combinations in cleaning and disinfecting agents with the following macro-families: alcohols, aldehydes, surface-active compounds (surfactants), halogens, oxidizing substances and acids and bases (Kramer and Assadian, 2008). Resistance data provided by the manufacturers are only suitable for a rough assessment and must be followed by practical tests.

The sound absorber must be designed and optimized in terms of optimal cleanability. This refers to the shaping (geometry), its connections and joints, its installation and assembly elements and the surface finish and its tightness against internal areas, e.g. by avoiding gaps, seams, sharp edges.

Approach

Identification and selection of surfaces and construction materials with optimum acoustic properties and compliant with hygiene requirements.

First, materials had to be sought which show resistance to disinfectants, since the surface always has to be resistant against the constituents of surface disinfectants. Since practical tests are essential (Ehrenstein and Pongratz, 2008) though very time-consuming (e.g. through adjusting the wipe disinfection over a longer period), both the construction materials and the disinfectants had to be reduced to a small number by means of pre-selection so that the chemical stability of the materials could be established. On the basis of literature references and manufacturers' specification as to material compatibility (Sastri, 2010), a conventional cleaning agent on the basis of quats and a fast-acting detergent were selected as well as construction materials for practical tests.

Acoustic transparency depends on (low) sound density or mass, and their stiffness. Stainless steel which is often used in medical devices is not available in the form of the required thin layers with sufficient width (of perforation?). The same applies to glass foil, particularly since the latter is also unpractical and expensive for the use in sound absorbers. This meant that only plastic materials were suitable to provide the microbiological barrier.

For the daily routines in hospitals, a certain mechanical robustness and scratch-resistance is necessary, especially when foils have to be applied on the outside, around the cassettes. Various types of plastic materials showed strengths, which did not only depend on the thickness of the layer, but on the material itself. But also, the processing of the material matters, e.g. polypropylene (PP) foil appeared initially to be rather soft for the purpose as it scratches easily by contact with fingernails, however as a stretched version (O-PP) with surface treatment, the mechanical strength is significantly higher. A (stretched) PET foil presented much better characteristics, while PVF foil, though chemically highly resistant, turned out to be less suitable due to low mechanical stability, and moreover it is rather expensive. After sampling various foils, some were selected for acoustic tests. Additional tests (fig. 1) examined chemical stability, the microbiological barrier and disinfectability (Gebel et al, 2001).

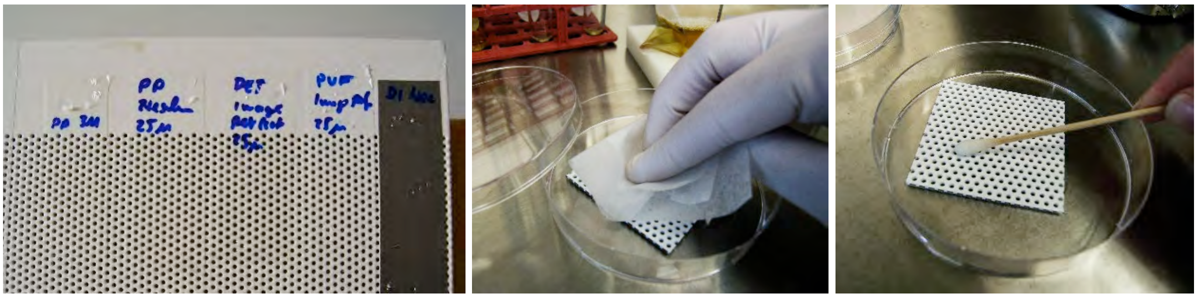

Fig. 1: Testing for scratch resistance/mechanical stability of plastic foils as well as the chemical stability and desinfectability of materials.

After analysis of the test results, the PET foil Mylar A with a thickness of 50 µm was chosen. This foil proved to be chemically stable and it provides a sufficient microbiological barrier. Measurements of the acoustic absorption properties provided satisfactory results i.e. covering the core of the absorber impaired the absorption only insignificantly [Kirch and Pottgiesser, 2016].

To meet the regulatory hygiene requirements on the sound absorber, certain aspects needed to be considered [Kramer et al, 2012]. On the side which requires disinfecting treatment, there must be no cuts or overlapping of foil. Overlapping creates areas which cannot be reached, while cuts might cause leaks. The edges of the foil or bonding layer need to be placed in an area where no disinfection takes place. Therefore, the approach was to develop a geometry for the housing which would allow mantling with foil which would require neither overlapping nor folding. This would be given by using a folded volume from one surface. The surface would thus remain intact. The housing can be wrapped without any cuts or overlapping and without the need to shrink-wrap the foil, a measure which always leads to ripples. The edge of the foil is moved to the rear area so that after wall-mounting and sealing of the joint, an area remains on the front with an intact surface that can be disinfected. This means that the disinfectant does not come in contact with the adhesive at the foil edges. It is important hereby that the edges all rest on the wall. After experimenting with this principle, geometries were worked out in detail and converted to paper models. (Fig. 2, 3).

Fig. 2: Samples of schematic models for the housing: Geometries of volumes, folded from one face.

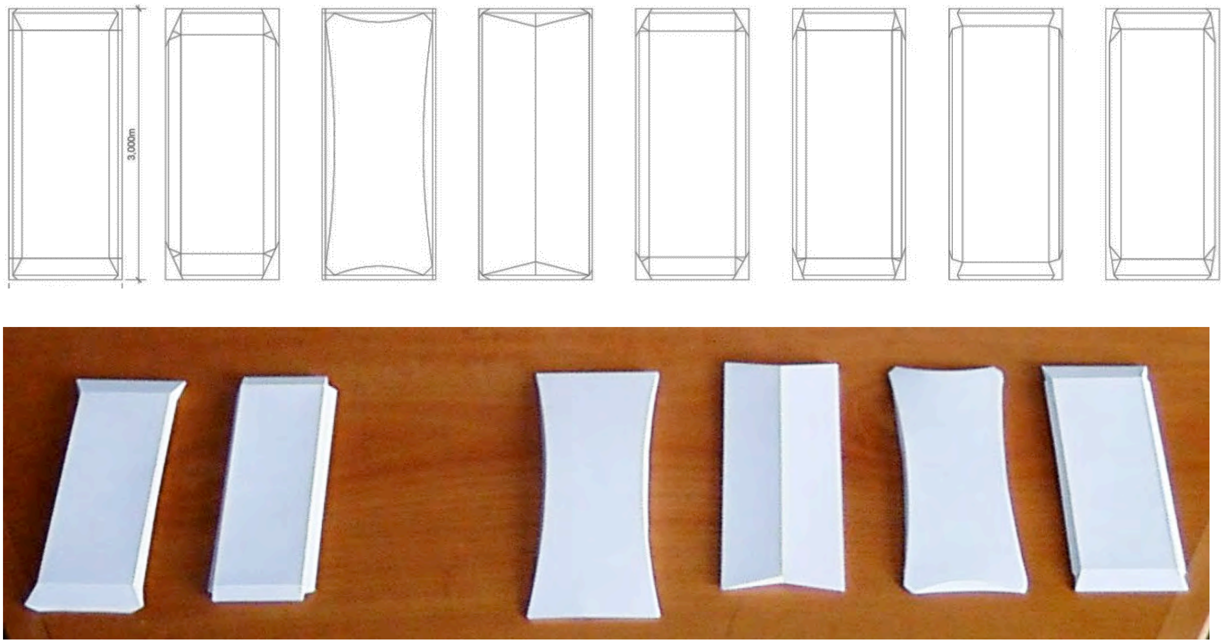

Fig. 3: For the sound absorbers, geometries that can be folded from the surface in the process (above) and as folded paper models of the geometries (below).

Designing an architectural integration based on status analyses

Medicine has developed into a service sector and health services have turned into consumer products. As a logical consequence, the trend in hospital architecture is towards more comfortable rooms with hotel character, a trend which should influence the design of sound absorbers. This allows for absorbers to be integrated easily at a later stage and for an uncomplicated retrofitting, the installation of the sound absorbers as a model was requested by the project partner.

Existing clinical architecture was analyzed with regard to the formal design and available areas for later installations, to show which installation options would typically lend themselves for the purpose. Installation variants were tried out with visualizations, which showed designs for sound absorber housings and their layouts. Here it was possible to try out how the different geometries and their arrangement could be included in various logical spatial contexts and also their effect (fig. 4).

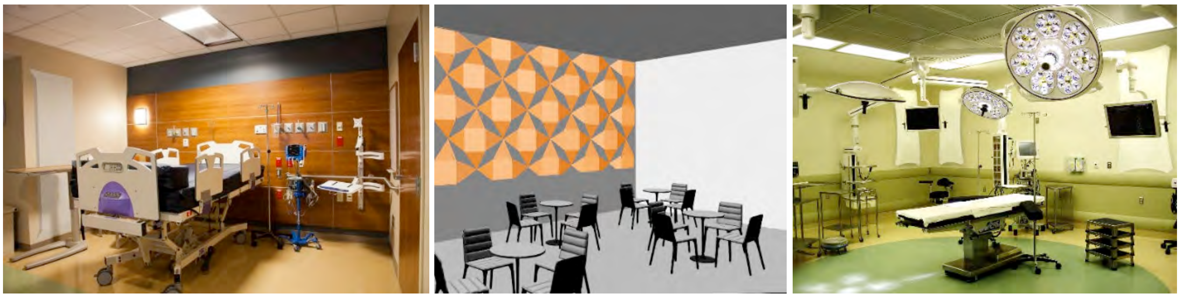

Fig. 4: Sample visualizations of different installation options of the sound absorber cassettes

Implementation of the design

After development of the form, the search started for suitable materials and methods for the production of the sound absorber housing. Deep-drawing of metal was no option for economic reasons, since the tool production would only amortise over high-volume production numbers. This led to the attempt to manufacture the housing from simple folding plate materials. Not only should the material allow folding, perforation should also be possible to let sound enter the cassette. Plate materials, in particular sandwich plates can be routed from the back to define the folded edge. This is known as routing and folding technique and is used e.g. for façade cassettes in aluminium compound sheets (Dibond). Tests were also carried out with aluminum sheets and plastics materials suitable for cold-bending (PC and PET-G) and where material thickness was routed (fig. 5).

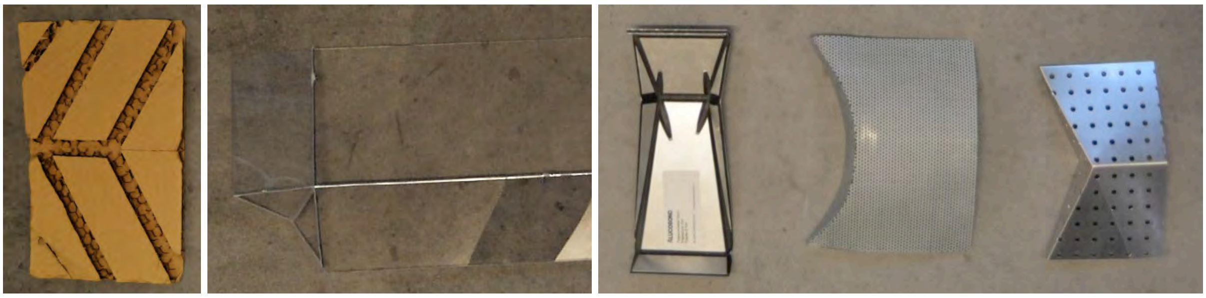

Fig 5: Functional model for different types of foldable housing materials.

After tests with functional models, scaled-down proto-types of folded cassettes were produced from aluminum composite panels, to test the suitability for the production of housing. (Figs. 6 and 7).

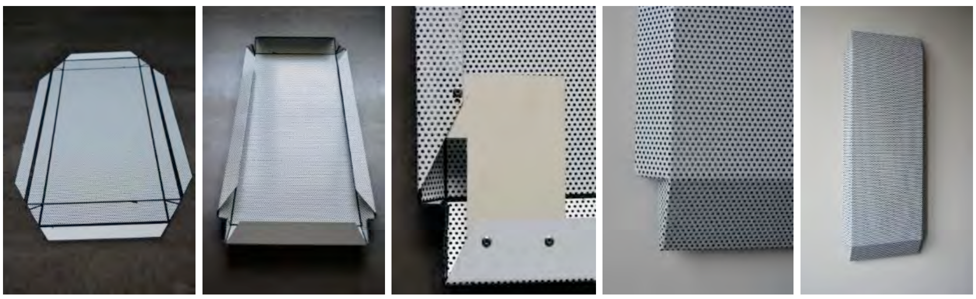

Fig 6: Prototype made of aluminum composite sheets, with routing and folding technology and corner bracing.

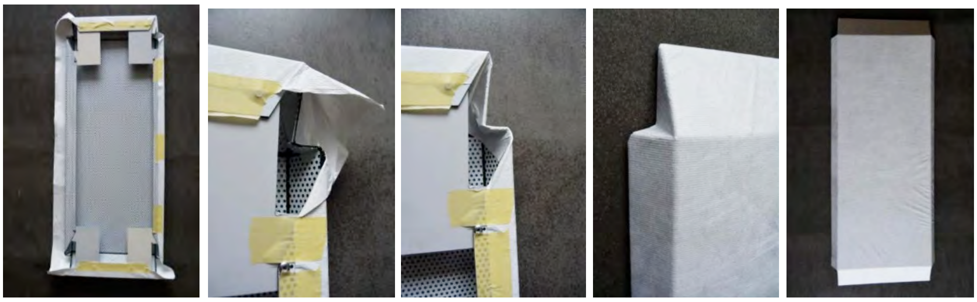

Fig. 7: Covering the prototype with PE fleece, with details of the inward fold of the foil at the inner corner (bottom). The bonding surfaces/foil edges have been moved inwards.

At the cassette, a fold is created by the material thickness where the foil is turned inwards at the edge and there it cannot be smoothly wrapped also because of the tough, rigid foil materials. This was easier to solve with the curved variant (fig. 8).

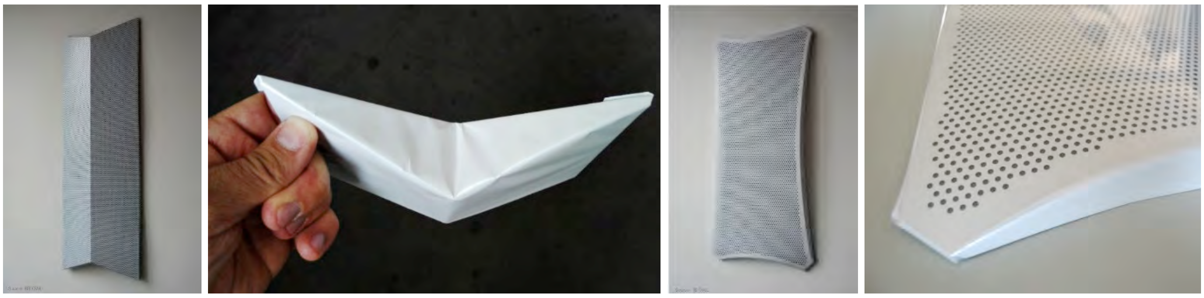

Fig 8: The edges which are turned inwards cause unevenness (left). Variant with arched edge with foil cover (right).

Since the edges of the cassette rest on the wall with a 90° angle, a flap is missing at the rounded edge to facilitate the mounting, which is only possible with the variant with the straight edge. Moreover the composite sheets led to spring tension effects at the folding edges which led inturn to retraction and imprecise geometry. The folding process also causes problems: All folds need to be achieved at the same time – a process which is not possible to carry out manually with the required precision and not doable at all at standard turning benches or in a press brake process. This would require a special 5-axle controllable robot which does not promise to be a cost-effective solution.

All these reasons led to a new approach: the housing will be made in cubic shape which allows an efficient manufacturing process with simple edging tools. The housing will remain open at the short edges so that the foil wrapping can be drawn inwards there. (Fig. 9).

Fig. 9: Detail of corner solution for the foil wrapping. The foil is drawn inwards through the open corner.

Since joints have to be sealed anyway at the point where the housing meets the wall, this joint needs only to be extended around the short housing edges where the foil turns inwards. In this way, it is possible to choose a tried and tested manufacturing process for the housing in order to wrap the same later with foil, without causing pleats or overlaps. Special adhesive tape needed to be found for the fixing of the foil to the sound absorber cassette, in particular since the powder coating of the cassette has poor adhesive properties and the adhesive tapes came off after a short while when put under tension during mounting. Good results were in the end achieved with an adhesive tape usually used for vapour barriers in buildings. This tape can be stretched lengthwise but not laterally. This is advantageous when wrapping the cassettes by hand with PET foil, which means that the inelastic PET foil can be applied without creating overlapping folds. Since the perforated sheet used for the housing shows a different thermal expansion coefficient than plastic foil, an additional foam adhesive tape is used on the back which offsets to some extent the different tensions.

The sound absorber has to be mounted tightly to the wall, according to RKI recommendation, this is to be done by applying a silicon sealant. Since the selected PET foil is a synthetic material, a sealing compound had to be found which is suitable for plastic materials. According to manufacturers' specifications (suitable for use in laboratories and food processing companies) silicones and an MS joint sealing compound were identified and purchased for suitability tests, in particular to test resistance to cleaning agents.

Trial results in real life settings

At the technology centre of the Life Science Technology department of HS OWL, it was possible to carry out a practical trial (fig. 10). After a successful installation and sealing of joints with silicone, the influence of reverberant time could be measured.

Fig. 10: Installation of a sound absorber in the technology centre of the department of *Life Science Technologies* at the University of Applied Sciences OWL.

Conclusion and Outlook

With a thin technical membrane, issues of acoustics and hygiene can be solved and suitable geometries allow efficient disinfection. It was possible to develop a product which complies with the requirements of hygiene, acoustics, material stability as well as design and construction and which thereby allows to optimize room acoustics in hospitals. There is increasing noise pollution in hospitals, nursing staff are retiring prematurely and there are multi-resistant germs, the spread of which should be prevented with consistent hygiene concepts. The same applies to office areas where noise pollution leads to a growing number of incidents of stress and burnout.

With better room acoustics (reduction of reverberation) more calm and better speech intelligibility can be achieved which in turn lead to fewer mistakes caused by stress and communication errors and to a lower basic noise level. [Fuchs, 2007]. Since sudden events and peaks are most distressing, it is possible to add soft(!) artificial noise in acoustically calmed areas which reduces the distance between background noises and sound peaks (i.e. sound masking) resulting in less stress. [Stanchina et al, 2005]. In hospital rooms these measures can result in better sleep quality and faster recovery.

Acknowledgments

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A Case Study on the Relationship between Urban Block Typology and Traffic Noise Distribution in High Density Urban Context

Ji Zhang[1], Stephen Siu Yu Lau[2], Chye Kiang Heng[2], Siu-Kit Lau[2], Hongzhan Lai[2]

[1] Solar Energy Research Institute of Singapore, National University of Singapore, hope.zh@gmail.com

[2] Department of Architecture, School of Design and Environment, National University of Singapore

Abstract: Traffic noise is among the main pollutions affecting the environmental quality of cities. This is particularly pertinent in the context of the cities in Asia and other regions where relative compact urban form as a result of high density urban development exacerbate the negative impacts of the ever-increasing traffic flows. This study investigate the impact of different building typologies on traffic noise distribution on both the horizontal level at pedestrian height for outdoor open space and the vertical level in front of building facades. Thirty generic urban block typologies representing different urban design strategies were analysed through noise mapping simulation study within a theoretically homogeneous context in which the conditions of the road traffic surrounding the site and the built density are fixed so as to control the source of noise and development density. Noise level obtained for outdoor open space with the site boundary at 2 meters height in a 2x2m horizontal grid and noise exposure level at a distance 1 meter away from façade in a 2x3m vertical grid along the façade surfaces were obtained from simulation using CRTN as the traffic noise calculation method. The findings indicate that there is a significant relationship between several planning and building geometry parameters and a variety of noise distribution performance indicators. The findings inform the planners and designers the key design factors that can be adjusted to mitigate the negative impact of traffic noise. This study also highlights the importance of performance evaluation in the early planning and design stage when the environmental performance can be optimized using different design strategies.

Keywords: Up to five, comma separated

Introduction

Traffic noise is among the main pollutions affecting the environmental quality of cities, which has been shown to have significant impact to the physiological comfort and psychological wellbeing of urban dwellers and to urban environmental quality in general (WHO, 2011). This is particularly pertinent in the context of the cities in Asia and other regions where relative compact urban form as a result of high density urban development exacerbate the negative impacts of the ever-increasing traffic flows.

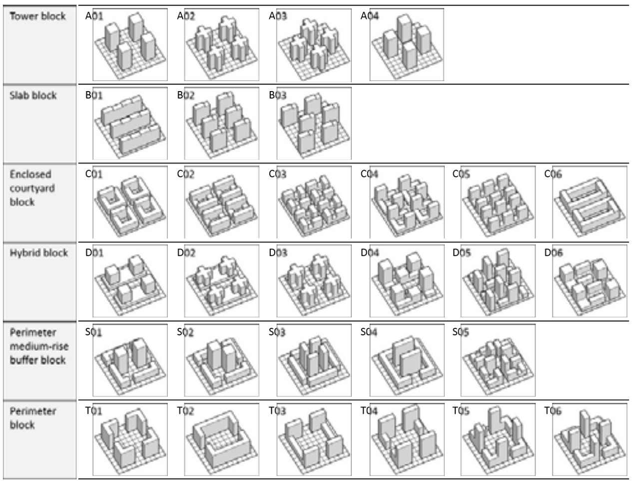
Various solutions, such as noise barriers and sound deflectors, have been implemented in many Asian cities to mitigate traffic noise pollution. However, most of them are costly afterthought measures and are not integrated with design of buildings and planning of urban infrastructures. There is a lack of studies on the planning and design factors that which shall be considered in the first place to minimize the impacts of traffic noise.

This study investigate the impact of different building typologies on traffic noise distribution on both the horizontal level at pedestrian height for outdoor open space and the vertical level in front of building facades. The objective is to identify the key urban planning parameters and building geometric variables that may help to formulate design guidelines for informed decision making in the early stage of planning and design to mitigate the negative impacts of traffic noise.

Method

Thirty generic urban block typologies representing different urban design strategies were analysed through noise mapping simulation study within a theoretically homogeneous context in which the conditions of the road traffic surrounding the site and the built density are fixed so as to control the source of noise and development density as shown in Figure 1 (Zhang et al., 2012).

For this study, the traffic noise exposure level as indicated by L10 (18-hour), i.e. the noise level exceeded for 10% of the period from 06:00 to 24:00 according to the CRTN method (Department of Transport Welsh Office, 1988), was simulated in the noise mapping software CadnaA (DataKustik, 2014) with one order of reflection considered. A validation study was conducted previously (Lau, Zhang, Lau, & Lai, 2016) and a strong and positive relationship between the measured and simulated traffic noise exposure levels was identified for measurement points along the road and that in front of the façade facing the road. In this study, noise exposure level for outdoor open space within the site boundary at 2 meters height in a 2x2m horizontal grid and noise exposure level at a distance 1 meter away from façade in a 2x3m vertical grid along the façade surfaces were obtained from simulation. A workflow was created in the Rhinoceros+Grasshopper software platform which integrate the functions of parametric modelling, simulation, analysis and visualization in a coherent and efficient manner.



Fixed Planning Parameters	
Floor Area Density (FAR)	3.0
Site Area (m^2)	10,000
Gross Floor Area (GFA) (m^2)	30,000
Width of Road (m)	15
Width of Sidewalk (m)	2.5

Fixed Simulation Parameters	
Width of Road (m)	15
Road surface correction (dBA)	-1
Total 18-hour Traffic Flows	15800
Average Traffic Speed (km/h)	31
% Heavy Vehicles	27.2
Order of Reflation	1

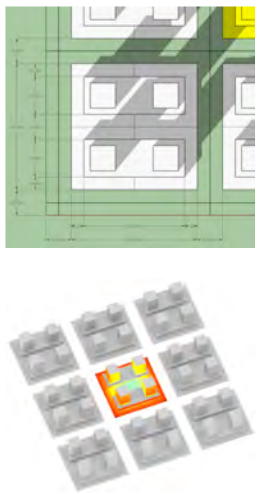


Figure 1. The thirty generic urban block typologies and the controlled study context.

Results

As shown in Figure 2, the typologies with relatively lower average ground and façade noise exposure levels include the enclosed courtyard blocks, perimeter blocks with medium-rise buffer buildings and the perimeter blocks. The buildings arranged around the peripheral of the site for these typologies may have effectively shielded the traffic noise surrounding the site, resulting in relatively more quiet ground areas and building façades for most of the spaces within the site.

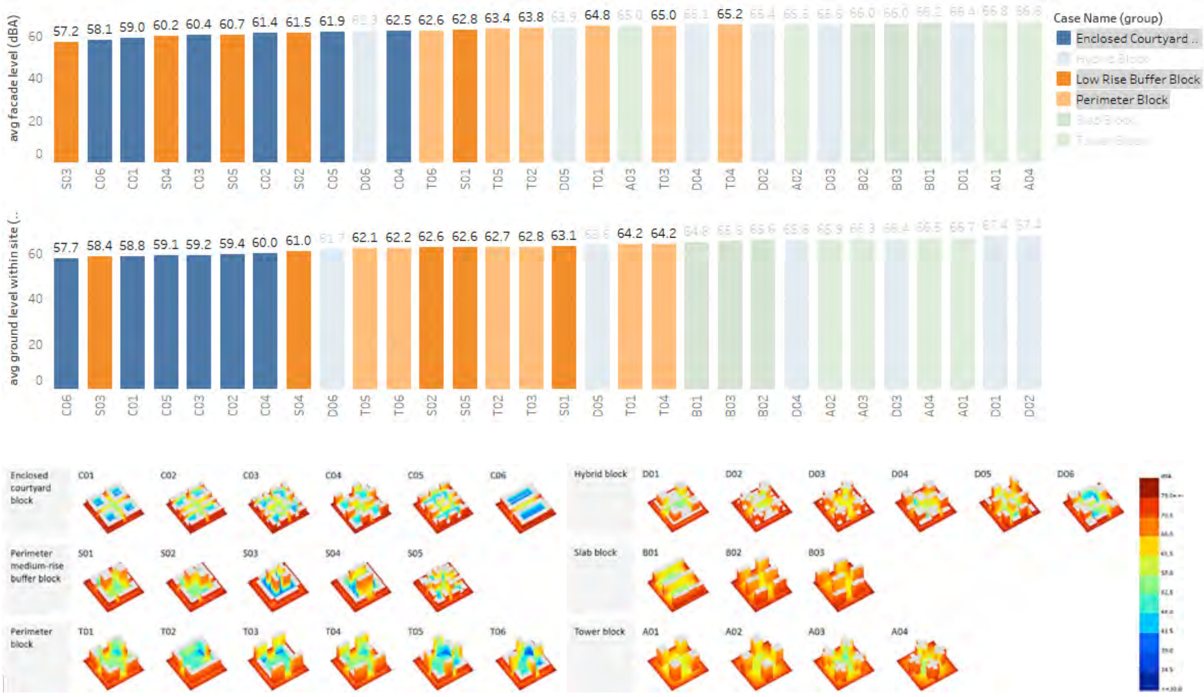


Figure 2. Urban block typologies with lower and higher average ground and façade noise exposure levels.

On the other hand, the typologies with relatively higher average ground and façade noise exposure level include the hybrid blocks, the slab blocks and the tower blocks. The relatively larger spacing between buildings and gaps between the buildings along the roads for these typologies allow traffic noise propagates relatively deeper into the site that may have contributed to higher noise exposure levels on both the ground open spaces and building facades. Depending on the urban block typologies been examined, the difference between the average noise exposure levels can be as high as 9.7 dBA and 9.6 dBA for ground and façade, respectively, as measured by L10 (18h).

Considering the potential impact of façade noise exposure level to interior spaces, the urban block typologies with relatively lower floor area normalized façade noise exposure level are shown in Figure 3, which include primarily the hybrid typologies, some cases from the enclosed courtyard typologies and perimeter blocks with medium-rise buffer buildings. However, other typologies within these three groups seem to have different façade noise exposure levels per unit floor area, and this might be attributed to the geometric characteristics of their building forms, such as compacity and floor depth, which is addressed in the next section. The typologies with relatively higher floor area normalized façade noise exposure level include primarily slab blocks, perimeter blocks and tower blocks. Depending on the urban block typologies been examined, the difference in floor area normalized façade noise exposure level can be as high as 4.2 dBA/m^2.

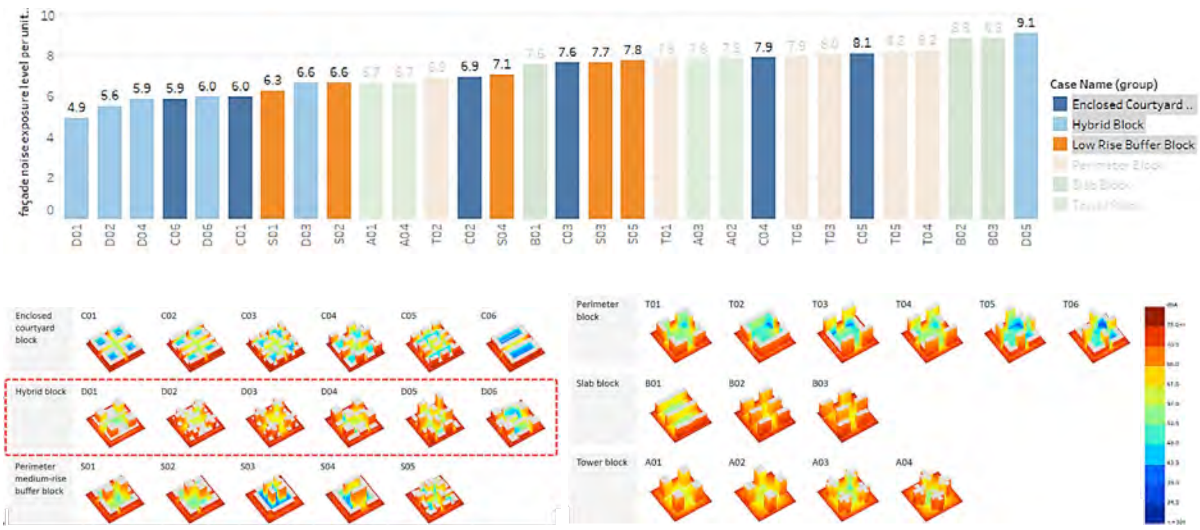


Figure 3. Urban block typologies with lower and higher floor area normalized façade noise exposure levels.

Bivariate correlation analysis was conducted for the 30 generic urban block typologies between the planning and geometric parameters and the performance indicators for both ground and facades. The significant correlations are highlighted in yellow color in Figure 4.

Performance Indicator	net building coverage (%)	compacity	avg APR (m)	OSR
% of ground within site >= threshold [%]	0.46	-0.40	0.53	-0.46
min ground level within site [dBA]	-0.53	-0.41	0.41	0.54
max ground level within site [dBA]	0.74	0.34	-0.36	-0.76
avg ground level within site [dBA]	-0.46	-0.54	0.64	0.47
90 percentile ground level within site (dBA)	-0.62	-0.45	0.49	0.62
50 percentile ground level within site (dBA)	-0.17	-0.49	0.66	0.17
10 percentile ground level within site (dBA)	0.86	0.24	-0.28	-0.86
% facade >= threshold [%]	-0.32	-0.58	0.47	0.34
min facade level (dBA)	-0.58	-0.41	0.40	0.60
max facade level (dBA)	0.46	0.35	-0.41	-0.45
avg facade level (dBA)	-0.51	-0.41	0.48	0.51
90 percentile facade level (dBA)	-0.59	-0.41	0.48	0.59
50 percentile facade level (dBA)	-0.54	-0.44	0.51	0.53
10 percentile facade level (dBA)	0.70	0.22	-0.30	-0.71
façade noise exposure level per unit floor area (dBA/m2)	-0.52	0.82	-0.76	0.49

Highlighted correlation is significant at the 0.05 level (2-tailed).

Figure 4. Significant planning and geometric variables for noise distribution performance indicators for the 30 generic urban blocks.

The impact of net building coverage on the different performance indicators vary a lot. Increasing building coverage is likely to result in higher ratio of overexposed ground area and higher maximum and 10 percentile ground noise exposure levels. Building coverage is negatively correlated with the other three ground noise distribution performance indicators, i.e. the minimum, average and 90 percentile ground noise exposure levels. Similarly, increasing building coverage may lead to higher maximum and 10 percentile façade noise exposure levels, and lower minimum, average, 90 and 50 percentiles and floor area normalized façade noise exposure levels.

Building compacity is negatively correlated with majority of the performance indicators, except floor area normalized façade noise exposure levels. On the other hand, average Area- to-Perimeter Ratio (APR) is positively correlated with most of the performance indicators, except maximum ground and façade noise exposure levels and floor area normalized façade noise exposure levels. The propensities of the correlations for compacity and that for APR are opposite to each other due to the negative correlation between these two geometric variables (R=-0.926). Similarly, the relationships between Open Space Ratio (OSR) on the performance indicators are almost exactly opposite to that for building coverage due to the significant and negative correlation (R=-0.993) between the two variables.

Linear regression analysis was conducted for the significant predictors of the average ground noise exposure level, and the results are shown in Figure 5. Average Area-to-Perimeter Ratio (APR) has the strongest and positive effect, and it can account for 41% of the variation in average ground noise exposure level. This is followed by compacity which has negative effect (R^2=0.29), Open Space Ratio (OSR) which is a positive predictor (R^2=0.22) and building coverage (R^2=0.21) which is a negative predictor. The results suggest that to reduce the average noise level on ground, the most effective design strategies in descending order, relatively speaking, include reducing building depth, increasing compactness of the building form, reducing open space per unit floor area, and increasing building coverage.

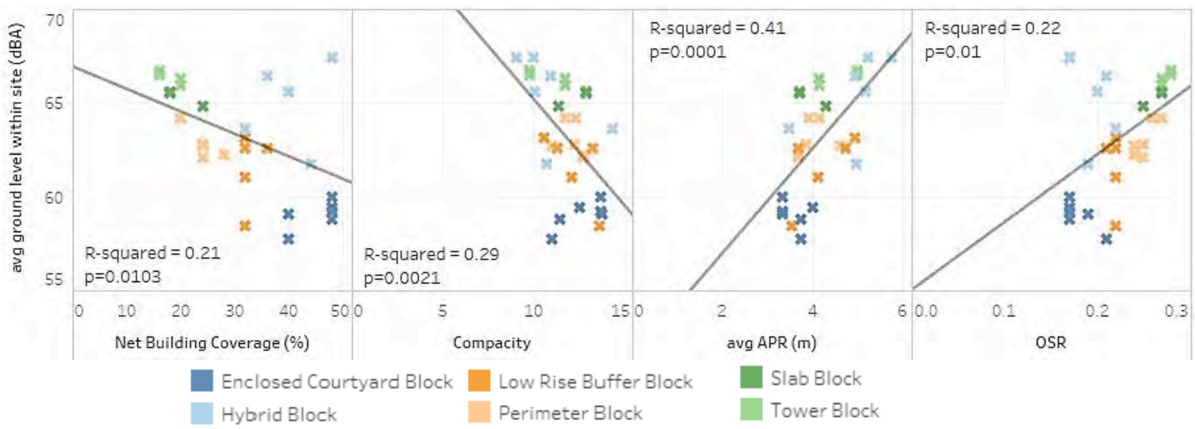


Figure 5. Significant planning and geometric factors for average ground noise exposure level for the 30 generic urban blocks.

The impacts of the four planning and geometric variables on the average façade noise level are in similar trend but to different extents as shown in Figure 6. Building coverage and Open Space Ratio have relative the strongest influences, though in different propensity, and each of them accounts for 26% of the variations in average façade noise exposure levels. This is followed by average APR (R^2=0.23) and compacity (R^2=0.17). The results suggest that to reduce the average noise level on ground, the most effective design strategies in descending

order, relatively speaking, include increasing building coverage or reducing open space ratio, reducing the depth of the floor plan, and increasing the compactness of the building form.

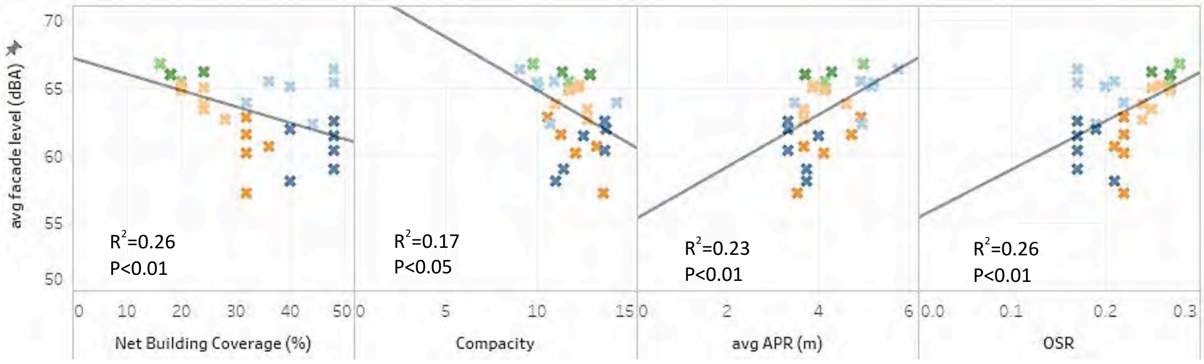


Figure 6. Significant planning and geometric factors for average facade noise exposure level for the 30 generic urban blocks.

Floor area normalized façade noise exposure level is a performance indicator that implies the impact of the noise receivable on facades to interior floor areas. The results of regression analysis for the significant predictor variables for this performance indicator area shown in Figure 7. Compacity is the strongest and positive factor which explains 67% of the variation in the floor area normalized façade noise exposure level. This is followed by average APR (R^2=0.57) and building coverage (R^2=0.27), both having negative effects. Open Space Ratio is the factor having the least impact (R^2=0.24). The results suggest that to reduce façade noise exposure level as shared for each unit floor area, the most effective design strategies in descending order, relatively speaking, include increasing the compactness and floor depth of the building form, increasing building site coverage, and reducing open space per unit floor area.

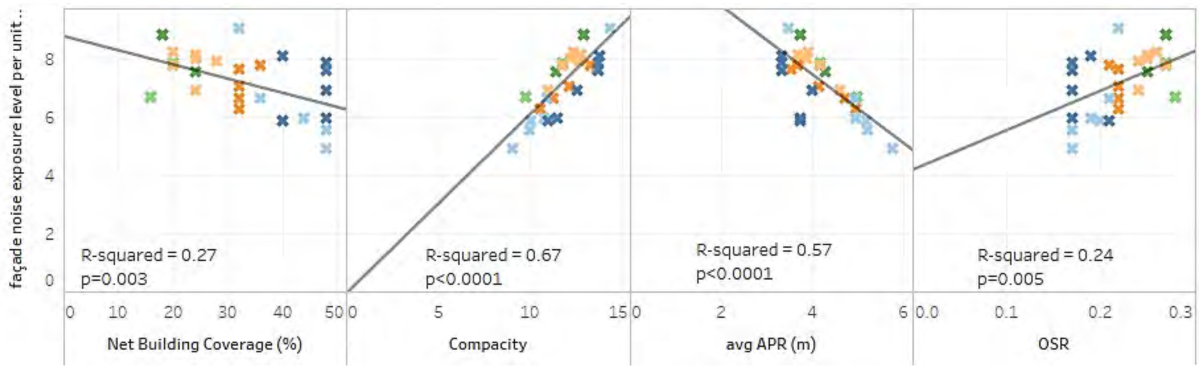


Figure 7. Significant planning and geometric factors for floor area normalized façade noise exposure level for the 30 generic urban blocks.

For the three performance indicators examined there, i.e average ground and façade noise exposure levels and floor area normalized façade noise exposure level, the propensity and magnitude of influence of the two planning parameters, i.e. building coverage and Open Space Ratio, are similar, the former having negative effects and the latter having positive effects and each accounting for 21% to 27% of the variance in the performance indicators.

The propensity and magnitude of influence of the two building geometric variables compacity and average Area-to-Perimeter Ratio vary to a greater extent, comparatively speaking. The variances in the performance indicators accounted for by the two variables range from 17% to 67%. For both the average ground and façade noise exposure levels, compacity and average APR are negative and positive predictors, respectively. However, if façade noise exposure level per unit floor area is considered, the impacts of the two geometric variables change to the opposite. This suggests that the observations on the impacts of certain design factors are dependent on the performance area been examined and the performance indicator adopted for evaluation.

Discussion and Conclusions

This study identified some of the key planning parameter and geometric variables that are significantly related to the traffic noise distribution on both ground and façades across different building typologies. The findings inform the planners and designers the key design factors that can be adjusted to mitigate the negative impact of traffic noise. This study highlights the importance of performance evaluation in the early planning and design stage when the environmental performance can be optimized using different building typologies and design strategies.

Acknowledgement

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Transition Communities

PLEA 2017 Conference

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Keith Baker

Peri-urban communities in transition: transformation scenarios of neighbourhoods towards sustainability

Judith Drouilles[1], Sophie Lufkin[1], Emmanuel Rey[1]

[1] Laboratory of Architecture and Sustainable Technologies (LAST), Institute of Architecture (IA), School of Architecture, Civil and Environmental Engineering (ENAC), Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland, judith.drouilles@epfl.ch

Abstract: The paper outlines the theoretical context and preliminary outputs of the investigation on the prospective evolution of existing peri-urban neighbourhoods of single-family houses toward lower carbon and more resilient communities, for 2050, in Switzerland. Embedded within the Helvetic territorial and administrative context, the paper introduces a multi-scale definition of "peri-urban residential municipalities", as a basis to set up a typology of peri-urban neighbourhoods of single-family houses. The typology results from the close observation of peri-urban neighbourhoods in Lausanne's urban region. It identifies five neighbourhood types among which five representative case studies are selected for the next steps of the research. The paper focuses on one of the most common types and presents the application of three exploratory scenarios of mid-term transformations on the selected case study. The current policy framework and multiple prospective studies about demographic dynamics, sustainable neighbourhoods, single-family houses adaptation, etc. are the main guidelines of the design process. The selected design paths investigate several scales of mutations, from the perpetuation of current life-styles to deeper social and environmental transformations. Finally, several indicators, proceeding from current major issues faced by the residential peri-urban neighbourhoods, highlight the performances and challenges of each scenario, through the spectrum of sustainability.

Keywords: Peri-urban, neighbourhoods of single-family houses, typology, prospective scenarios, sustainability.

Introduction

Peri-urban neighbourhoods of single-family houses are facing growing sustainability challenges. They are responsible for and subjected to numerous threats on different levels: environmentally, urban sprawl and landscape modification; economically, land fragmentation into small private properties, and services and public equipment funding; socially, individualism and segregation, and energetically, inefficient buildings and car dependency (Drouilles et al, 2016a).

The paper investigates the conditions for a sustainable peri-urban renewal. It aims at presenting some preliminary outputs about the design of exploratory transformation scenarios for 2050 of an existing peri-urban neighbourhood of single-family houses located in the periphery of Lausanne, in Switzerland.

Developed in four parts, the paper first presents a deeper understanding of the research object through the elaboration of a typology of peri-urban neighbourhoods of single-family houses. Then, it focuses on one of the most representative type of neighbourhoods and sums up the main features of the chosen case study. Third, it gives the theoretical framework for the design and application of three prospective scenarios on the neighbourhood chosen as case study (CSN). Finally, the current state and the scenarios are assessed through the three pillars of sustainability (environment, economics and society).

Research framework

Since the 1950s and the democratization of cars, urbanisation has spread farther around the main cities. Adopting new forms and combinations of land uses, the resulting "in between territories" (i.e. neither within the city-core nor entirely rural) are almost not defined. When attempting to delimitate clear territorial entities, we witnessed how unsettled were the existing definitions to set the limits of peripheral and peri-urban spaces. Statistical institutions, in France and Switzerland for instance, tend to consider only the daily commuting features, to determine the peri-urban or peripheral character of a municipality. Some limitations may emerge from the choice of qualifying peripheral municipalities entirely through the relation they maintain with the central city. Population densities (OECD, 2011; Eurostat et al, 2011) and land uses (Gonçalves et al, 2017) could represent resourceful complements to identify urban or rural influences, as well as specific features within the peripheral entity.

Two preliminary steps are necessary to elaborate a typology of peri-urban neighbourhoods of single-family houses. The first step has to do with the precise definition of the "peri-urban residential municipalities" territorial entity, which the overall research project investigates. An extended literature review has enabled the formulation of this six criteria definition highlighting the main recurrent peri-urban features of the post-industrial European city (Drouilles et al, 2016b). Considering the municipalities' location within the urban region, their specific demographics, and their building stock composition, the identified "peri-urban residential municipalities" are more likely to be burdened with increasing environmental, economic and social pressures, than any other peripheral area. In a second phase, the research project focuses on neighbourhoods of single-family houses located within the defined "peri-urban residential municipalities". The neighbourhoods' inventory and various statistical analysis in the representative urban region of Lausanne (Switzerland) resulted in the determination of five types of peri-urban neighbourhoods of single-family houses.

Current research on peri-urban areas reveals that the most significant issues are the building related energy consumptions and mobility aspects that derive from the lifestyles of peri-urban populations (Drouilles et al, 2017). These elements, in line with the broader ambitions of the research project, have influenced the choice and weighting of the variables for the elaboration of the typology. Three main variables were used for the classification of the neighbourhoods:

1- Distance to train station: Federal office for territorial development (ARE) provides some reference values to measure public transport accessibility quality (ARE, 2011). Farther than 1 kilometre, ARE evaluates the accessibility as inexistent. This distance represents a valid threshold in a peripheral context.
2- Date of neighbourhood's first constructions: setting a threshold in 1976 allows taking into account policies' evolutions, in terms of land use planning (Garnier, 1984) as well as energy efficiency. Following the 1970s' oil crisis, many European countries implement new regulations around the 1980s (Summerfield et al, 2015; Aksoezen et al, 2015).
3- Neighbourhood's size: we consider the effects of this criterion on the project design. The average size of neighbourhoods in Lausanne – 5 hectares – is set as threshold.

Five types of neighbourhoods of single-family houses in Lausanne's "peri-urban residential municipalities" emerge from the weighting of those three variables (Tab 1).

Table 1: Typology of peri-urban neighbourhoods of single-family houses in Lausanne
classification criteria and average reference values *(nbhd = neighbourhoods)*

Criteria	Type 1	Type 2	Type 3	Type 4	Type 5
Distance to train station *(km)*	< 1		> 1		> 1
First constructions	1950 - 1976		1950 - 1976		1976 - 2000
Nbhd size *(ha)*	> 5	< 5	> 5	< 5	< 5
Average values	*7 nbhd*	*7 nbhd*	*27 nbhd*	*42 nbhd*	*16 nbhd*
Distance to train station *(km)*	0.5	0.5	4.6	4.2	4.5
Nbhd size *(ha)*	16	2.7	10	2.2	1.7
Number of plots	134	23	82	19	13
Average plot size *(sqm)*	1’275	1’205	1’310	1’240	1’230
Dwelling units	157	28	88	21	15
Residential density *(dwellings/ha)*	9	10	8	9	10
Population density *(inhabitants/ha)*	24	27	22	24	24
Proportion of detached houses	68%	68%	71%	74%	74%

In most of the neighbourhoods (77%), the first constructions occurred between 1950 and 1976. We would like to emphasize that neighbourhoods of all types are bordered by agricultural areas on at least 40% of their perimeter. Residential density is relatively low: between 8 and 10 dwellings per hectares, mainly due to large private plots (average size of 1’250sqm) and a majority of single-family houses. The internal road network mixes mostly dead-ends and few local or regional roads bearing external traffic.

Types 1 and 2, thanks to their closer location to a train station, show a slightly more compact land use, i.e. a higher proportion of terraced houses. Types 3 and 4, the oldest and worst connected, gather 64% of the total amount of peri-urban neighbourhoods of single-family houses. According to our hypothesis, the latter are in a more delicate situation in relation to sustainability issues.

Type 3

In the scope of the paper, we focus on one of the most representative type of peri-urban neighbourhoods of single-family houses in Lausanne’s urban region (25%). Type 3 gathers older and bigger neighbourhoods that are badly connected to the regional public transport network. In average, the neighbourhoods sprawl on approximately 10 hectares and host more than 200 inhabitants. They present a lower density than other types: plots tend to be bigger, with an average value of 1’300sqm; some plots remain unbuilt and detached houses represent 70% of the building stock. They are also mostly isolated from other built-up areas, with natural or agricultural lands bordering three forth of the neighbourhood.

The chosen case study neighbourhood (CSN) is located in the municipality of Echichens bordering the city of Morges (the second city of Lausanne’s urban region). The municipality of Echichens has a population of about 2’500 inhabitants (2015). Formed as a result of the merger between four villages in 2011, the territory of the municipality is characterized by a dispersed urbanisation and the domination of agricultural land use (80% of the municipality’s area) (OFS, 2013). The CSN is composed of 61 private plots, among which are 26 detached houses, 24 plots with terraced-houses of two dwellings, 4 plots with multi-dwellings buildings, and 7 free and unbuilt plots. In total, about 245 people inhabit 93 dwellings and 119 people share the ownership. (Fig. 1- E0).

Scenarios

The object of the research project is the proposition of three prospective transformation scenarios of the CSN by the year 2050, which embody – for inhabitant and authorities – different ways to undertake changes. The current Swiss policy provides a strong framework for the scenarios' design, in particular the revision of the territorial planning law (2014), which contests urban sprawl and promotes urban renewal and densification processes (CH, 2013). Its regional application (Etat de Vaud, 2016) implies that:

1- The city centres and the well-connected sectors in the urban regions will absorb most of the future demographic growth. Outside those strategic areas, i.e. where the CSN is situated, the aim is to limit growth rate at 0.75% per year.
2- No more natural or agricultural land should be lost to built-up areas.

Consequently, all three scenarios assume the same population growth of 65 inhabitants (+26.5% by 2050) and implement CSN's transformation within its current boundaries. The following scenarios represent an exploratory phase of the research. They explore the CSN's internal transformation from an exclusive residential approach. At this stage, contextual issues such as mobility, work and leisure aspects are not addressed. For future works, this suggests a wide margin of improvement with more advanced scenarios.

The common starting point of the scenarios design is the identification of over-sized plots and dwellings that are likely to generate economic issues for their owners, in terms of maintenance and retrofit, as well as sale or inheritances.

First scenario S1 (Fig. 1 – S1)

The scenario follows the current trend of evolutions in neighbourhoods of single-family houses. The transformations result from the implementation of individual and private initiatives on each private property, mainly led by economic motivations. It implies three types of actions, such as i) daily maintenance but no significant retrofit, ii) low carbon retrofit and iii) densification: house extension or subdivision, dwelling substitution, plot subdivision, etc. (Fawcett, 2014; Beyeler, 2014; Bosshard et al, 2014).

The housing demand by 2050 is exclusively addressed by the construction of new single-family houses or the subdivision of over-sized existing houses. The main actors are the owners and real-estate developers in case of over-sized plots, and the targeted households are families

Second scenario S2 (Fig. 1 – S2)

Local authorities play a significant role in the CSN's renewal. They guide and frame individual and private initiatives and help shifting from transformations at plot scale to planning at neighbourhood scale. Internal mobility issues are also managed at the neighbourhood scale to unlock dead-ends and provide a variety of public spaces and direct paths for pedestrians. Local authorities enable the construction of new building types and smaller and more affordable dwellings. They encourage new stakeholders to take part in the neighbourhood planning and smaller households to invest and stay in the neighbourhood.

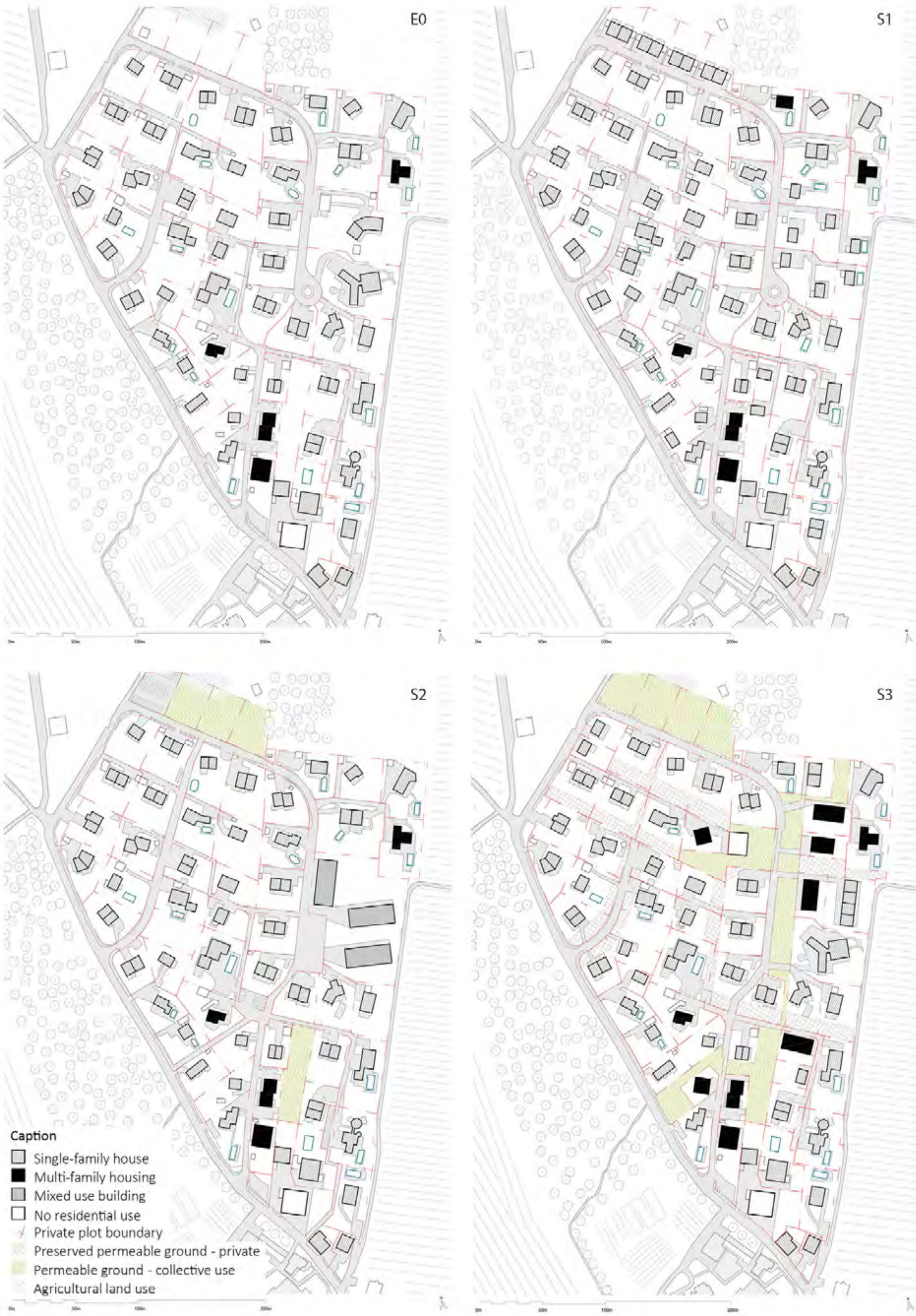


Figure 1: Current state (E0) and three prospective transformation scenarios of the CSN (S1, S2, S3)

Public planning enables private-public partnerships. A unique project answers the housing demand and provides enough capital gain to enhance an ambitious redistribution of internal circulations and collective areas, as well as the preservation of existing green grounds and the creation of car park areas. The main challenges are related to the regulation of private initiatives.

Third scenario S3 (Fig. 1 – S3)

Also led by local authorities, the CSN's renewal seeks to address the issue of loss of green grounds through densification processes and the question of biodiversity quality of both domestic gardens and farmed landscapes (Goddard et al, 2010). Town planning regulation indicates private permeable ground to be preserved and kept unbuilt. Additionally, the mutualisation of green community spaces allows the accentuation of a green corridor within the neighbourhood and provides an example of "wildlife-friendly" garden-management. Many mechanisms of land compensations and density bonuses are required to preserve non-constructible areas and compensate every involved private owner.

The intervention's direct effect is a more significant densification. Local authorities may also regulate the densification with housing requirements targeting smaller households. The actions generally improve the quality of the living environment by opening fences and managing nature at neighbourhood scale. Local associations could manage common areas; oversee management and pedagogy.

Preliminary assessment

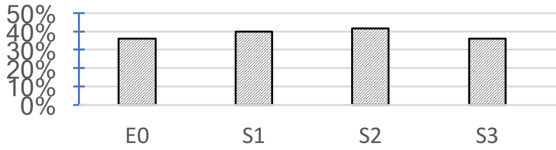
This preliminary assessment takes into account only a short list of indicators, which relate to the three pillars of sustainability. They are chosen to assess the performance of each scenario as well as the current state of the CSN. When final scenarios are assessed, in future works, more elements will be added, such as neighbourhood's energy performances evaluations, which will be compared to the "2'000-watt society" requirements (Drouilles et al, 2017).

Environment: proportion of impermeable ground (SIA, 2004) within the entire neighbourhood (Fig. 2a) and within the private plots only (Fig. 2b)

The proportion of impermeable ground underlines the effects of horizontal densification in S1, with an increased proportion by 4% within the entire neighbourhood and within the private plots. The results for S2 at neighbourhood scale are explained by the creation of new paths, streets and places. S3's intentions of preserving green ground are achieved, with a proportion that remains stable in the neighbourhood between E0 and S3 despite the construction of new buildings. At the scale of the private plots, the proportion is equal in S2 and S3 and lower than S1's.

Economic: average plot size per household (Fig. 3a) and living area per person (Fig. 3b).

The economic indicators show, for each scenario, a reduction of both the plot size and the living area compared to current state. Therefore, purchasing and selling real estate should result easier and more affordable due to an overall moderation of the real estate value. S2 and S3 present the most promising situations with significantly smaller dwellings or plots.



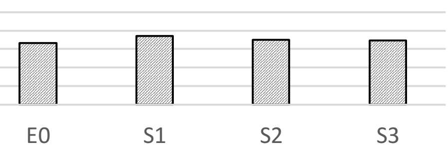


Figure 2a: Proportion of impermeable ground in the neighbourhood

Figure 2b: Proportion of impermeable ground in the private plots

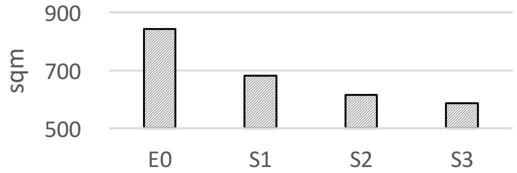


Figure 3a: Average plot size per household

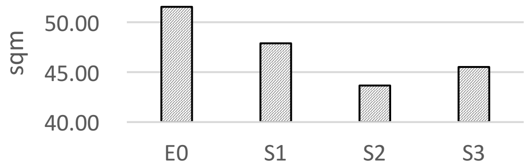


Figure 3b: Average living area per person

Social: diversity of building types (Fig. 4a), and diversity of dwelling sizes (Fig. 4b).

Finally, the social indicators show on which residential segments the scenarios focus their development. S1 follows E0's trend regarding building types, and probably also in terms of sociocultural profile. S2 and S3 are more likely to present a higher social mix, at least in terms of generation and household types, with the development of mixed or multi-family buildings. Regarding dwelling sizes, S2 focuses on smaller dwellings, i.e. less than 100sqm, while classic single-family houses between 100 and 150 sqm are still the common practice in S1. S3 favours the construction of a dwellings' diversity in the multi-family buildings, from small apartments for smaller households (less than 60sqm), to medium units for families (between 100 and 150sqm).

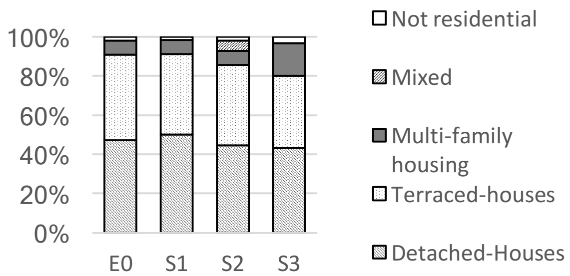


Figure 4a: Building types (building stock)

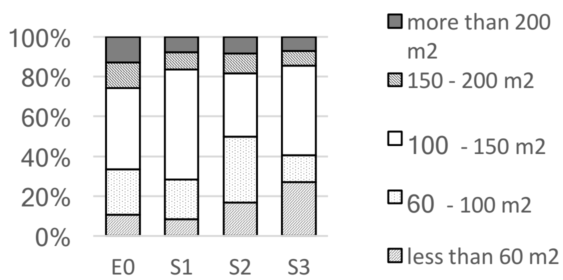


Figure 4b: Dwelling types (dwelling stock)

Conclusion

The exploratory transformation scenarios applied to an existing peri-urban neighbourhood of single-family houses are meant to enrich our ongoing research about sustainable peri-urban futures. The trend scenario (S1), which implements a progressive horizontal densification, highlights the difficulty to control individual initiatives. Regulation or public guidance could help to surpass transformations happening at the scale of private pots and depending on individual economic interests (Beyeler, 2014). The scenarios implementing a neighbourhood planning (S2, S3) give some clues to consider a sustainable renewal of peri-urban neighbourhoods. Their strengths rely on the preservation of green grounds or on the development of diverse and affordable housing that are likely to support the shift towards lower carbon and more resilient peri-urban communities.

Although they still raise many questions especially regarding their feasibility, those exploratory scenarios provide some elements that can be built upon in the next steps of the research. Embedded within the Swiss policy framework, the scenarios illustrate the limitations of changes implied by a regulated demographic growth and the importance of retrofit actions to reduce the buildings' environmental footprint since the major part of the current building stock persists until 2050. To address the future development issue of every type of peri-urban residential neighbourhood, a deepening of the assessment is imperative. The prospective transformation scenarios applied to all case studies will also have to address broader aspects of accessibility, work and leisure-related motilities, energy and economic performances, etc.

Acknowledgements

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PLEA 2017 EDINBURGH
Design to Thrive

Real estate and sustainable construction: Private perspectives for progress in energy regulation of a liberalised market

Felipe Encinas[1,2], Carlos Aguirre[3] and Carlos Marmolejo[4]

[1] Escuela de Arquitectura, Facultad de Arquitectura, Diseño y Estudios Urbanos, Pontificia Universidad Católica de Chile, Santiago, Chile, felipe.encinas@uc.cl
[2] Centro de Desarrollo Urbano Sustentable (CEDEUS)
[3] Escuela de Construcción, Universidad de las Américas, Santiago, Chile, caguirre@udla.cl
[4] Centro de Política de Suelo y Valoraciones, Escuela Técnica Superior de Arquitectura de Barcelona, Universidad Politécnica de Cataluña, Barcelona, España, carlos.marmolejo@upc.edu

Abstract: In real estate markets such as Santiago de Chile where energy efficiency certificates are not mandatory, incorporating solutions that respond to the growing demand for sustainability entails a natural tension between their acceptance as necessary measures and the way they are addressed by the market. Under this mechanism, the market has introduced housing features that are communicated individually through real estate marketing. Energy efficient elements are more commonly seen in higher-end homes, where they are treated as standard features, while they are still considered innovations at the lower end of the housing market. However, it has been shown that energy efficient features decline in relative importance over time, ceasing to be considered marks of distinction. In contrast, energy efficiency certification shows great potential for generating a proposal to create sustainable value over time, particularly due to its ability to objectively communicate a buildings' energy performance. This suggests that this model should be reviewed from a public policy perspective, with the understanding that the current voluntary standards must compete with other features, in addition to improving the minimum required standards.

Keywords: real estate market, real estate marketing, energy efficiency certification, sustainable features

Introduction

In most countries, home energy efficiency beyond certain minimal requirements has been left largely to the dynamics of the real estate markets at the residential level. In certain cases, this regulatory requirement is supplemented by required energy efficiency certification, which typically takes the form of ranking by categories, giving rise to labelling (Pérez-Lombard *et al.*, 2009). The European Directive on Energy Performance in Buildings has introduced the universal use of energy certificates in the European housing market (Official Journal of the European Union, 2003). This policy aims to provide energy transparency in real estate transactions so that the public can make more informed purchase or leasing decisions. This method banks on the indirect promotion of more energy-efficient buildings, as it is believed that their lower energy use costs will convince consumers to pay a premium for them, thereby offsetting the higher production costs and encouraging real estate developers to build them.

The real estate market of Santiago de Chile was selected as a case of a liberalised market where energy efficiency certificates exist as a tool but are not mandatory in housing transactions. In general, the housing market in Chile has a low government presence, which was defined by López-Morales, Gasic and Meza (2012) as “pro-business urban planning”. The country has, however, adopted regulations – in a prescriptive manner – that affect the energy performance of residences. In 2000, the rules known as the "Thermal Regulations" established requirements regarding maximum permissible thermal transmittance for roofs, while the 2007 update added requirements for thermal conditioning of perimeter walls, windows and ventilated floors (MINVU, 2016). While these standards have been welcomed as an initial effort, their actual contribution to household savings in energy efficiency is suboptimal (Collados and Armijo, 2008; Bustamante *et al.*, 2009), as they have not been updated in 10 years. In the case of Santiago, for example, this regulation defines 1.9 W/m^2K as the maximum permissible thermal transmittance for perimeter walls, which can be achieved by building thicker brick walls rather than by using thermal insulation. The OECD itself, to which Chile belongs, has addressed the matter, strongly recommending that the country improve its standards for thermal envelope (Caldera, 2012). Nonetheless, the "Energy Rating," an instrument that evaluates a home's energy efficiency, has been in use since 2013. While plans originally called for the system to be implemented gradually as a requirement beginning in 2016 (DITEC, 2015), this was postponed indefinitely, becoming a voluntary practice. Furthermore, the market has been very slow to adopt the system. For example, of all the homes that have achieved the final rating, only 5.4% are private market homes, which, in absolute terms, translates into 404 homes in all of Chile from the system's introduction in 2013 to October 2015 (MINVU, 2015). This is clearly a minuscule fraction of the total national housing stock, which has fluctuated between 70,000 and 90,000 units during the same period (CChC, 2016).

Given that the national market has not widely adopted any objective tool such as the energy efficiency rating to inform consumers of energy efficiency in real estate transactions, the approach to communicating the competitive advantages of energy efficiency or sustainability has been to treat it as one of the home's marketing features. These can be defined as the characteristics of a real estate product that differentiate it from other homes, adding to its aggregate value. As defined by Lancaster (1966), housing is desired not in and of itself but as the sum of each real estate product's features, where the most important have a greater impact on determining preferences and choices (Jansen, 2011), according to the compensatory logic of trade-offs. Thus, from the buyer's perspective, the price of a home is based on two points: the features the buyer requires (associated with the image of the future home) and the buyer's purchasing power (associated with future debt). It is therefore possible to propose an approach that observes and values property features based on what they contribute to this model. This observation is contextual and therefore analyses the set of features of an existing known supply as a whole, with the advertising emphasis determined by each supplier.

This article aims, first, to describe how the real estate market adopts and advertises energy efficiency and sustainability in a context where energy efficiency certification is not compulsory. Moreover, it seeks to assess whether a proposal can be formulated for the construction of long-term sustainable value based on the logic of the features proposed by the residential market in Santiago de Chile, and whether this is the best option for encouraging the adoption of sustainability in construction.

Methodology

The methodology of this study consists of using two approaches to investigate property features. First, to perform a cross-sectional analysis of features by geographical area, two submarkets in the city of Santiago were selected. While both are becoming increasingly densely populated, there is a significant difference in the forms of development they exhibit. While the submarket of Santiago Centre, the historic centre associated with middle-income residents, offers one- and two-bedroom apartments with a significant amount of infrastructural features (such as gym, multi-purpose room) and mid-level finishes, highlighting their proximity to public transport, the Las Condes Avenue submarket is entirely distinct. In the latter neighbourhood, located in the eastern part of town and associated with higher-income residents, buildings generally have a lower average height, larger size, high-end finishes and prime locations. For both cases, the entire supply of apartments was collected during the second half of 2016, based on their website, printed and billboard advertising. Additionally, a survey of housing applicants in these sectors was conducted, inquiring about the level of importance they attached to each of the property features listed. Second, a longitudinal analysis of the evolution of the various sustainable features in real estate marketing was undertaken by cataloguing all advertisements appearing between 2012 and 2016 in the "Housing and Decoration" magazine of the newspaper *El Mercurio* and the "Houses" supplement of the newspaper *Publimetro*. The former is a national newspaper, while the latter is a free publication with circulation restricted to the city of Santiago. A total of 7,290 advertisements were catalogued and examined for mentions of various features as well as the degree of importance attributed to each.

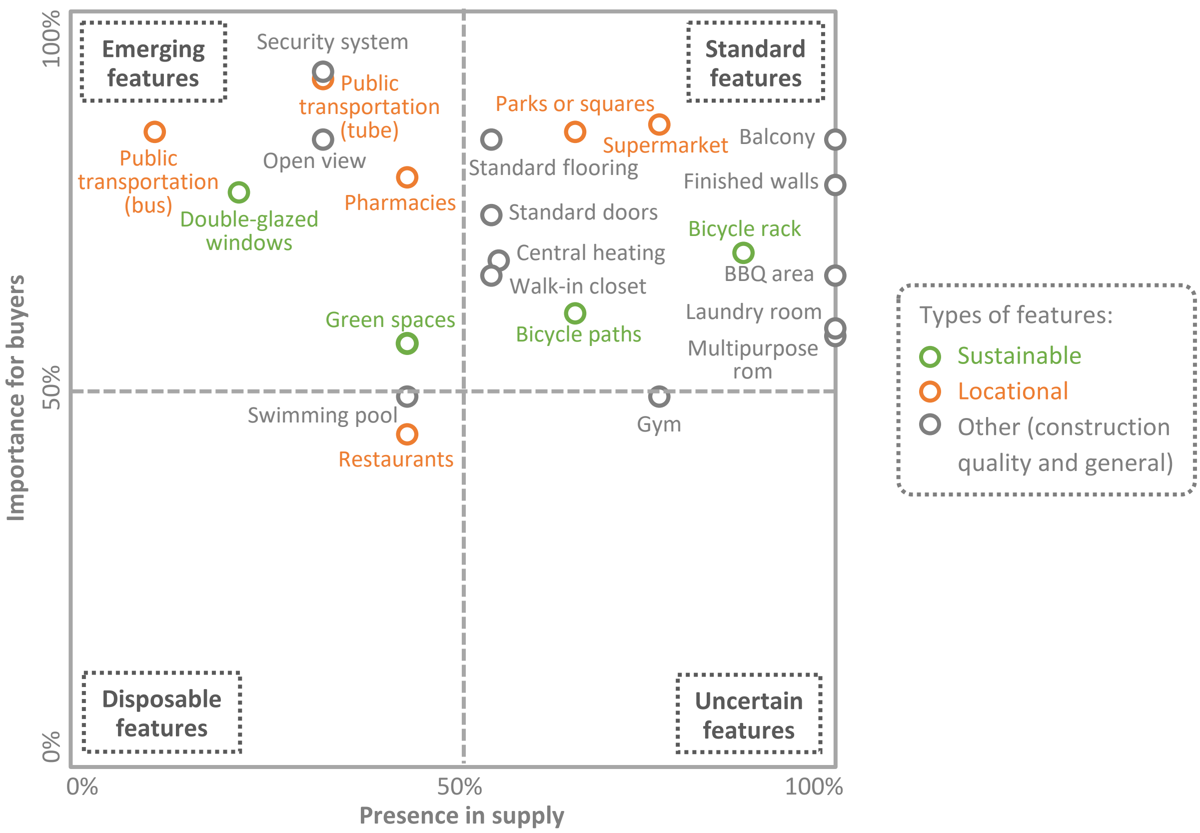

Figure 1. Value of features on the supply and demand sides for the Santiago Centre submarket

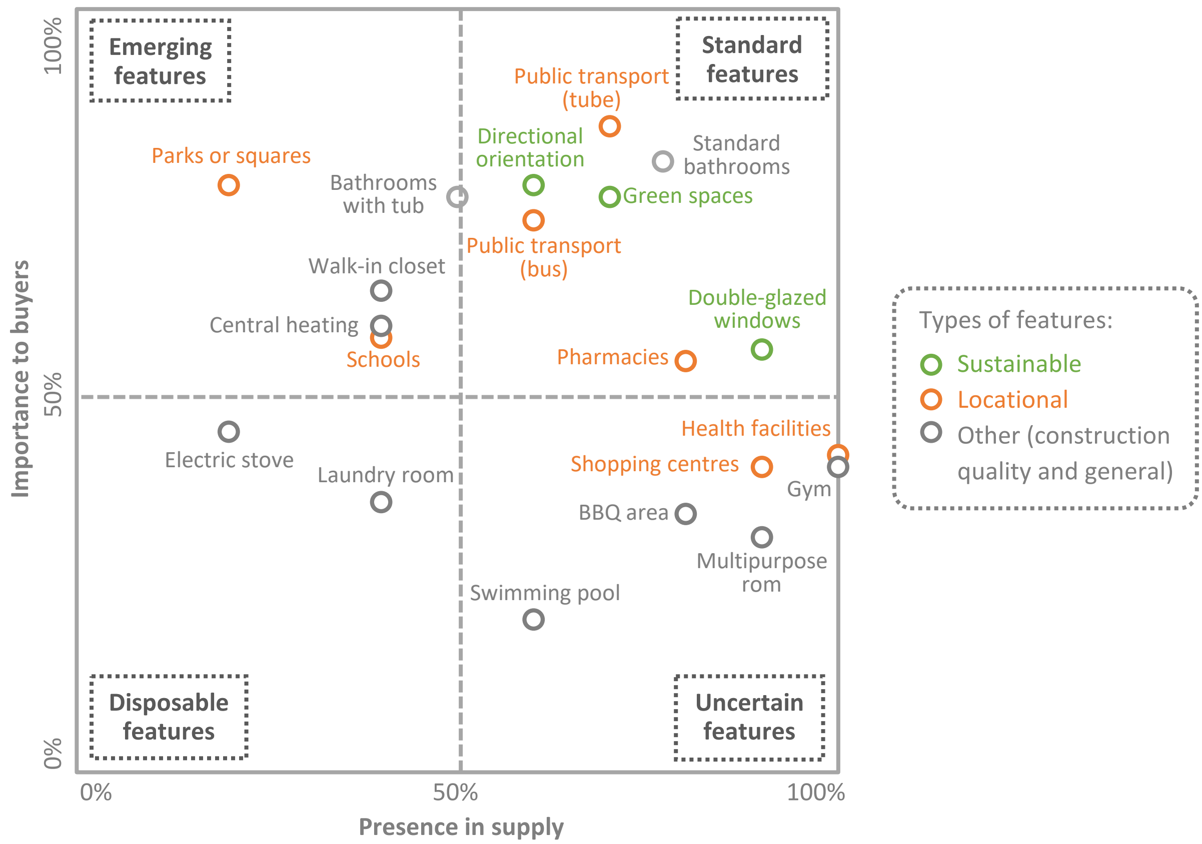

Figure 2. Value of features on the supply and demand sides for the Las Condes Avenue submarket

Results and discussion

Cross-sectional analysis of features offered and sought

Figures 1 and 2 present the assessment of supply/demand for various features in the two submarkets. These figures show how the features are strategically positioned in four categories, expressed as quadrants: standard features (high presence on the supply side and high importance on the demand side); emerging features (low presence on the supply side and high importance on the demand side); uncertain features (high presence on the supply side and low importance on the demand side); and disposable features (low presence on the supply side and low importance on the demand side). It may be observed that the features in each quadrant vary between the two submarkets at the same point in time, from which one can infer that the submarkets display different positioning strategies and different values among their consumers. In the case of Santiago Centre, the business strategy relies on pricing and is oriented mainly to investors, while on Las Condes Avenue, the strategy is clearly one of differentiation and meeting the consumer's desires. Accordingly, it can be inferred that the way sustainable features are positioned differs by neighbourhood and is associated with the strategies for different submarkets. For example, in Santiago Centre, these features may be present and highlighted whenever they may enhance value without significantly increasing the price. Thus, the sustainable features of a "bicycle rack" (very low cost) and "bicycle paths" (an external feature) are the only items positioned in the standard features quadrant in this case (Figure 1). In contrast, for the Las Condes Avenue submarket, sustainable features that add value to the real estate product ("double-glazed windows," "green spaces", "directional orientation") become standard features even when they raise the price of the property (Figure 2). However, there exists a risk of *greenwashing* wherever the project's sustainability (and therefore its marketing) is based solely on individual features without validated information, particularly when the minimum standards for energy efficiency are very low.

Longitudinal analysis of sustainable features in real estate marketing

The results obtained for the total number of projects in the real estate marketing database present an overview of the sustainable features mentioned in the advertisements. The five most commonly mentioned terms related to sustainability are "double-glazed windows" (5.4%), "solar panels" (5.3%), "energy efficient" (4.5%), "bicycle rack" (2.3%), "sustainable" (2.1%) and "energy efficiency certification" (1.9%). While the percentage of overall market penetration is relatively low, the complexity of the real estate market suggests that this ranking may appear differently in different market categories. For the purposes of this study, the price categories will be defined as under £70,000; between £70,000 and £130,000; and over £330,000. These segments represent buyers with different purchasing power, and in a city as residentially segregated as Santiago de Chile, they also correspond to different neighbourhood submarkets. Broadly speaking, the under £70,000 category and the over £330,000 category correspond to the submarkets of Santiago Centre and Las Condes Avenue, respectively.

Figure 3 shows the development of how two features have been positioned in real estate advertising aimed at these different price segments. It may be observed that the feature "double-glazed windows" appears prominently in advertising aimed at the high-end market at the beginning of the period studied but declines in prominence over time for that price range; by the final semester, "double-glazed windows" is mentioned more frequently in advertising to the under-£70,000 category than in high-end advertising. This may be explained by the fact that such features become expected standards in high-end construction, particularly in a context where weak minimum requirements diminish such features' capacity to provide differentiation. However, the popularization of this feature may favour lower-priced homes, which are capable of assuming the higher associated cost. In contrast, the feature "energy efficiency certification" appears almost exclusively in the higher-priced segment studied, where it remains prominent throughout the study period.

Finally, it is relevant to examine the results regarding the prominence of different features, as data on their presence and importance may shed new light on the evolution of real estate marketing's approach to sustainable construction. Thus, the findings on the "double-glazed windows" feature reveal a critical situation: while initially appearing in the higher and middle importance categories, these energy efficiency features were completely relegated to the category of low importance by the final year of the study (Figure 4). The exception is the "energy efficiency certification" feature – in this case, mainly related to the "Energy Rating" and LEED certification – which maintained its level of moderate importance. This highlights the considerable potential of multi-dimensional certification models for guiding the communication of supply in terms of sustainability, rather than the attributes being presented as a function of one single feature.

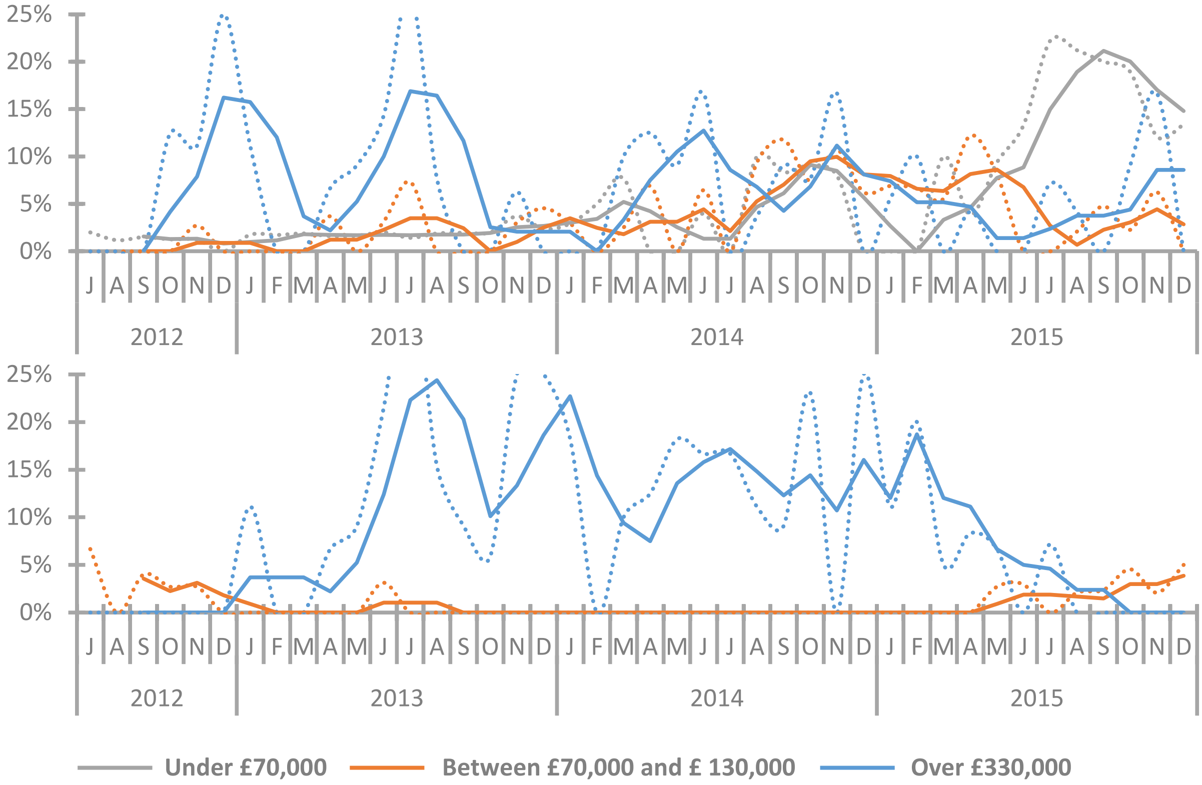

Figure 3. Presence of the features "double-glazed windows" (above) and "energy efficiency certification" (below) in real estate advertising by rolling quarter according to housing price range

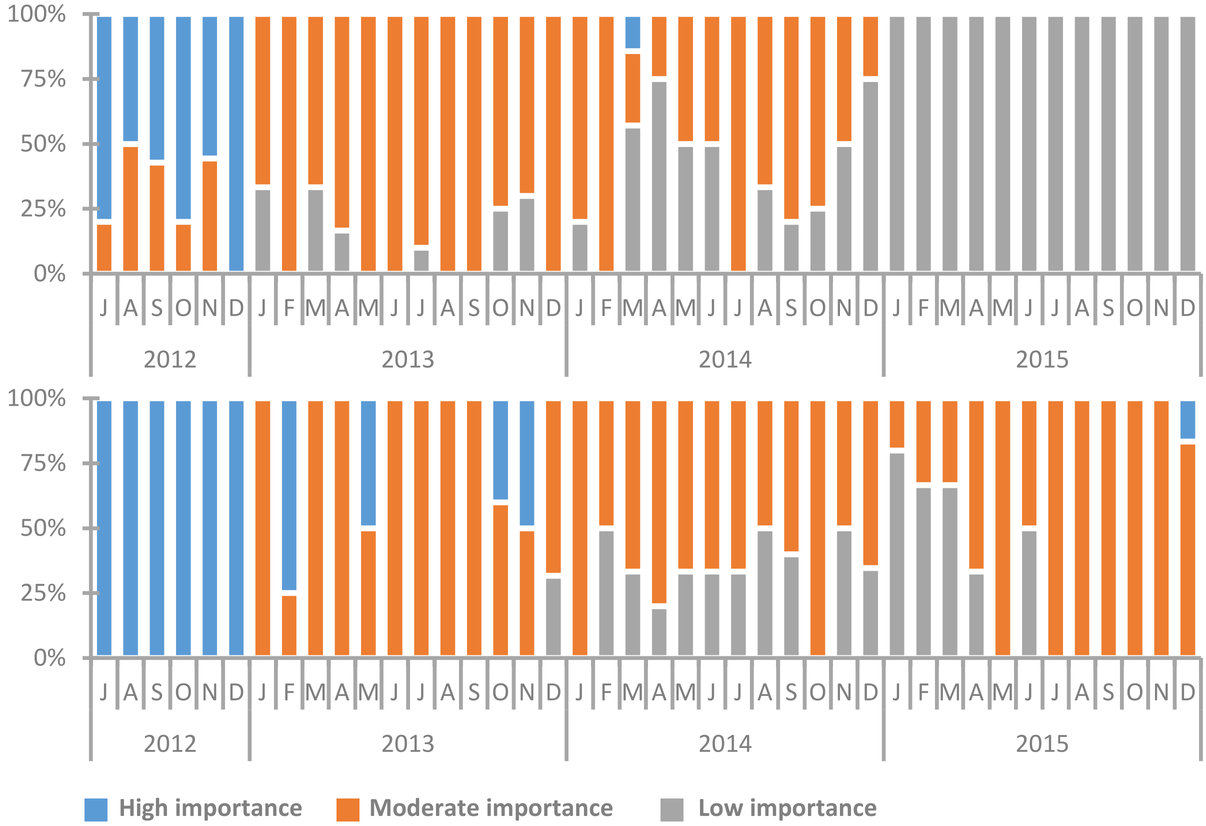

Figure 4. Level of importance of the features "double-glazed windows" (above) and "energy efficiency certification" (below) in monthly advertisements

Conclusions

The logic of attributing and promoting features associated with real estate stems from the perception of how these add value to the product and, therefore, increase its demand. Therefore, the industry gauges how consumers value each feature. This assessment of value differs for each of the submarkets, which in a city as residentially segregated as Santiago de Chile also entails segregation by housing prices. Thus, developers interpret these features differently, promoting them according to the segment where they are most competitive. Buyers, for their part, generate a type of zero-sum balance of trade-offs between their purchasing and borrowing power and their assessment of the value of each of the property's features. This accounts for how the buyer understands, recodifies and values the advertising stimulus.

At first reading, most sustainable features appeared more prominently in higher-income markets (defined as standard features in the cross-sectional analysis) than in lower-priced markets, where features (such as bicycle racks) that do not significantly affect the developers' profit margin were highlighted. However, longitudinal analysis revealed that over time, these features were gradually included among the standard expectations for a building, losing their relative importance as a mark of distinction and thus their prominent place in advertisements. Thus, "energy efficiency certification" is virtually the only feature that has the potential to maintain its role as a mark of sustainable construction over the long run, particularly due to its ability to provide the buyer with an objective measurement of a building's energy performance, overcoming the asymmetries of information affecting consumers. International experience, in particular with respect to European energy certificates, suggests that these instruments are indeed capable of encouraging the market to move towards supplying real estate products with higher levels of energy efficiency, as noted in the market premiums associated with homes that receive the highest energy efficiency ratings, as has been noticed by Bio Intelligence Service, Lyons and IEEP (2013), Fuerst *et al.* (2013, 2016), Gelegenis *et al.* (2014), de Ayala, Galarraga and Spadaro (2016) and Marmolejo (2016).

In addition, having weak minimum standards for energy performance creates easy access to minimal improvement that does not actually represent a significant contribution to energy efficiency, opening the door to greenwashing. Thus, improving the minimum required standards set out in the new national thermal regulations could boost competitiveness not only within the market, generating better products in terms of quality and post-sale service, but also among suppliers of constructive solutions and energy efficient technologies. Furthermore, the advertising-focused approach adopted in this article suggests that policies on energy efficiency certification should be reviewed, as the current voluntary approach forces energy efficiency certification to compete with other features on equal footing (compared, for example, with location, which is very important to certain middle-income buyers). Finally, the results show how information asymmetries are also segregated, with different housing submarkets attributing different degrees of value to sustainability. Public policy should be sensitive to these differences, in particular because at the lower end of the market, there is a much closer relationship between sale price and real estate financing that limits how much buyers can pay for housing.

Acknowledgements

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Design to Thrive

The Role of Intermediaries in Transitioning Photovoltaic Systems into Low Carbon Housing

Ziyad Frances[1, 2] and Fionn Stevenson[1]

[1]School of Architecture, University of Sheffield, Sheffield, UK, Western Bank, S10 2TN
[2]Department of Architectural Engineering, Koya University, University Park, Erbil, Kurdistan Region of Iraq

Abstract: Housing is responsible for one-third of CO_2 emission in the Western world, yet there is still limited understanding of why housing often uses up to three or more times the amount of energy than predicted by simulation, resulting in a performance gap. Previous studies have examined the role of various intermediary actors (both human and non-human) in shaping the professional governance of PV systems only in the provision stage, this study combines Actor Network Theory (ANT) and Practice Theory to explore the role of these intermediaries, or/and other intermediaries, during the occupation stage, a vital omission in the previous PV studies. To achieve this aim, 38 semi-structured interviews and 18 video tours were used in 6 case study housing projects in the UK (4 participative and 2 non-participative projects). Key findings indicate the significant role of the non-human intermediaries in impacting the system design and use beside human intermediaries. PO was the most significant human intermediaries in both the design and use stages, while FIT, location and aesthetic values were the key non-human intermediaries. New intermediaries are needed in particular for the utilisation of PV products, practices, and energy use management.

Keywords: Photovoltaic, implementation gap, energy transition, intermediaries

Introduction

Climate change presents a critical international challenge and opportunity to achieve a successful energy strategy and carbon emissions reductions in the built environment (NHBC, 2015). Homes are responsible for one-third of all energy consumption and CO_2 emissions in the Western world (DECC, 2013). Despite efforts to install domestic low carbon energy generation technologies, there is still limited understanding of why the predicted energy savings are not being achieved creating a significant performance gap between the predicted and use (Gram-Hanssen et al., 2016).

This performance gap is related to the way *occupants* use energy in their homes (Gram-Hanssen et al., 2012), and to occupants' limited understanding of these technologies (Stevenson et al., 20113, Brown & Gorgolewski, 2015), as well as the poor capacity of policy and standards to deliver the projected energy performances (Baborska-Narozny et al., 2016). Further studies detail the role of *provision actors* in shaping the material configuration and integration of these technologies, and occupant use as a result (Gram-Hanssen et al., 2016).

The UK government aims to develop new collective governance and action between multiple actors including, government, industry and community groups (Moss, 2009). This is to encourage wider user participation in governing their building environment and to produce solutions that respond to their preferences and capacities, which can improve the use of home technologies and reduce the implementation gap (Chang & Taylor, 2016). Community housing projects provide an optimal condition for understanding the collective and individual governance by users of their home environment. Governance here is defined as "the sum of all ways in which individuals, public agencies, and private organisations govern their common affairs in a continuous process of negotiation and cooperation" (Commission on Global Governance, 1995: 4).

I*ntermediaries* are broader agents who can also shape governance through their impacts. They can either impact actors agency or their capacity to do an action (Parag & Janda, 2014). For example, the home owner may have agency to decide to install a photovoltaic (PV) system, but the capacity might be low due to lack of money, knowledge and social support as intermediaries. Both human and non-human agencies performing as 'intermediaries', can have a critical impact on the decisions made by PV professionals during the PV system design stage (Frances & Stevenson, 2017). The main aim of this paper is to further explore the various intermediaries impacting the PV system in operation and practice, and identifying which key roles and impacts have been sustained from provision stage to occupation stage, and why.

The next section of this paper shows how Latour's Actor Network Theory (ANT) can be integrated into the framework of Schatzki's Practice Theory in order to conceptualise a sociotechnical phenomenon (Reckwitz, 2002) relating to the governance of PV technology in homes. This is then translated into methods in the next section. Next the findings section summaries the key intermediaries that impacted PV design during the provisioning stage, while the detailed discussion section shows how further intermediaries enrolled in the network and shaped occupants' interaction with PV appliances. The conclusion brings all these issues together and outlines some key recommendations.

Actor Network Theory and Practice theory

ANT examines how actors (both human and non-human) are enrolled in networks to achieve particular goals (e.g. PV design and use), and suggests that actors only shape their agency (the ability of doing an action) through their *relations* with other actors in a network (Latour, 2005). This process is defined as a 'sociology of translation', where the action of an actor is not fixed in form, but subject to 'a series of transformations' as a result of the negotiation of conflicting priorities and visions embodied in a variety of actors who are enrolled in a specific network (Latour, 1999). Various intermediary actors frame the agency and action of occupants when using their PV systems through the network of relations between them. Intermediaries are passive entities in an actor network that "transports meaning or force without transformation" (Latour, 2005: 39). Their priorities are decided by 'mediator' actors, who have governed the system design and influenced the subsequent use (Hodson et al., 2013). Crucially, the term agency is ascribed to both human and non-human actors (Callon, 1986). This opens an analytical space to examine non-human actors as significant intermediaries in a network, beside human intermediaries, who impacted PV system design and use.

Schatzki's (2002) Practice Theory goes further than ANT and aims to understand the *actual* application of a phenomenon within its real *context*, and explores the co-evolving of different elements that are significant to any practice: product, know-how, rules, and engagement (Gram-Hanssen, 2011). Those elements have crucial implications in this paper in terms of identifying and understanding further non-human intermediaries that impact the governance of PVs.

Research design and methods

A mixed methods empirical case study approach (Yin, 2013) was used to identify the governance of PV provision and use in two sets of contrasting housing projects across England. The four selected 'Participative community' (PC) housing projects (A-D) each had a representative 'Provisioning Occupant' (PO) as a key decision maker in the PV provision process. Two 'Non- participative community' (NPC) housing projects (E-F) had occupants who bought and lived in houses constructed by a developer without their involvement in the PV procurement process and no PO.

38 semi-structured interviews and 18 ethnographic video tours (Pink, 2009) were carried out with occupants and PV professionals, to illustrate the PV provision and use practices. The innovative home *video* tours (Stevenson & Rijal, 2010), developed from an ethnographic walkthrough method commonly used in an energy and building context, enabled the researchers to observe and understand the actual occupants' perceptions, practical knowledge and skills when using their PV controls in different contexts (Pink & Mackley, 2012). All interviews and video tours were, recorded, coded (Schreier, 2012) and linked to mapping (Yaneva, 2012) which is entirely novel. This is to understand the different capacities of actors in each case study when governing the PV system design and use, and to uniquely compare the governance structure between the two contrasting sets of housing projects.

Findings and discussions

PV provision stage intermediaries

In the PC projects, the POs performed both mediator and intermediary roles during the PV provision process. They made the key decisions during their discussions with other professionals, while also acting as intermediaries by passing on decisions to the occupants. The project manager acted as an intermediary in project A, impacting the decisions of the PO in terms of achieving the designed Code for Sustainable Homes (CSH) by passing on specified government policies and requirements. In projects B, C, and D, the installer made all the PV decisions with the PO because the PV system was independently installed from the main building construction. However, in projects A, he acted as an intermediary by only installing the equipment that has been specified and selected by the mechanical engineer. Surprisingly, the architect only acted as mediator in project A, while in the other projects, he performed as a passive intermediary by maintaining the assembly of the network. The mediating grant bodies required a monitoring system to be installed (C, D) and determined the overall size of the PV systems (D). In the NPC, the service consultant was the only human intermediary that impacted the decision of the client and the main contractor in project F, by passing on the assumptions made by PV installers in terms of cleaning requirements, which resulted in non-accessible PV panels.

In terms of non-human actors, professional knowledge proved to be the most significant intermediary in terms of impact (all projects), followed by standards and ethics (NPC projects), and FIT, environmental motivation and aesthetic (PC projects). In terms of knowledge, the professional *assumptions* about PV system interaction clearly reduced the potential role of the POs in terms of deciding the system affordance and occupants' capability to interact with these systems effectively as a result. The Feed in Tariff (FIT) standard intermediary clearly impacted the PV outcomes in the PC projects in terms of scale, system design and the installation time frame - all designed to improve the energy generation from the supply side and to increase the financial benefits. By contrast, the FIT had no impact on the system design in the NPC projects; instead, the CSH energy standard and developer ethics usefully impacted the developers' decision to install PV systems in the first place, and greatly impacted the scale of the systems alongside other intermediaries, such as the roof size and cost. The next section moves on to explore how these intermediaries further impacted occupants use of their PV systems. Figure 1 illustrate the different intermediaries that impacted the decisions made by professionals who acted as mediators.

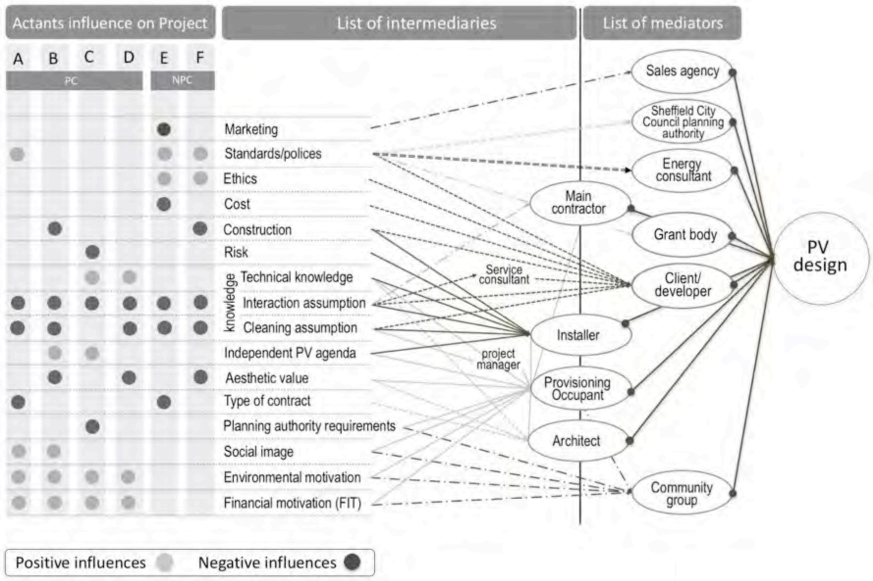

Figure 1. Professional and Occupant intermediaries during provision stage

PV interaction stage intermediaries

Non-human intermediaries

Nine non-human intermediaries were identified in all projects: Four existing ones from the provision stage (location, aesthetic value, ethics and FIT) and five new ones (cost, digital forums, skill, graphs and social structure) (Figure 2).

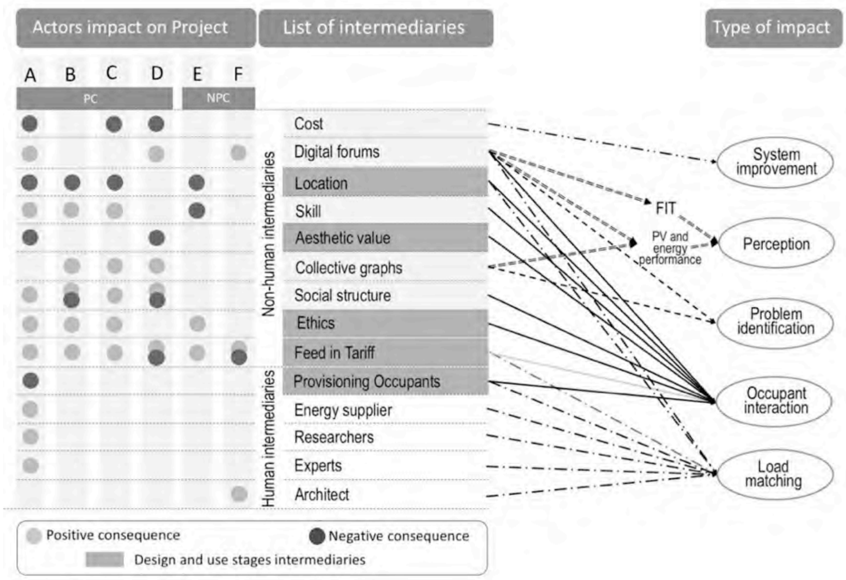

Figure 2: Intermediaries impacts on occupants during interaction stage

- *Feed in Tariff (FIT).* FIT was the key continuing intermediary in terms of occupant's interaction with their PV meters in all the projects with rules stating that occupants had to send their meter reading every three months to their energy supplier company to claim the financial payback from their system. Because two tenant occupants were unable to claim the FIT (E), they had no interaction with the meter and did not know if the system was working or not. The high rate of the FIT stopped three occupants (D, F) from managing their energy loads appropriately: *"…the issue of whether we use energy during the day or not was not so important because the attraction was the FIT. The FIT was very high"* (F4).
- *Social structure.* Allocating responsibilities for PV monitoring and cleaning the PV panels to a community member/group ensured occupants record of their energy generation through the read of PV meters in all PC projects and monitoring loggers (C, D), cleaning all the PV panels (C) and observing all the PV inverters (B). By contrast, this stopped the other occupants in project B from individually monitoring and understanding their own PV system performance. Allocating individual responsibility for occupants to maintain their house disabled three occupants in project D from cleaning their dirty PV panels because they could not afford to.
- *Location.* The hidden location of the inverters in projects A and B, and the invisibility of the PV energy generation monitor in project C significantly discouraged the occupants from observing these hidden appliances in order to match their energy load. The problem was worst in the NPC-project E, where three participants were not aware of their invertors: *"I don't know anything about it? What it does look like…I have never seen this thing in the house"* (video tour E1).
- *Skill.* Occupants interaction with the appliances that require some know-how to interact with them, such as the display screen of the inverter (A, B), and downloading the data from the monitoring loggers (C), worked because they had the skill in the first place. By contrast, occupants' limited understanding of using their energy monitoring device (E), led to ignoring it despite its load matching potential *"I don't interact with it because I don't know much about its application"* (Video Tour E1).
- *Collective graphs.* The collective PV and energy performance graphs, as a new intermediary, in the PC projects, enabled occupants to understand the relative performance by comparing their energy results with the results from neighbouring houses: *"So, individually we looked at the figures and compare the results…we have detected the problem of underperformance of our PV system and asked for suggestions"* (D1). Lack of publishing these graphs to all the community members (A) resulted in a surprisingly low rate of PV and energy performance awareness despite carbon reduction being a significant aim of the development.
- *Aesthetic values.* The occupants' aesthetic values overruled energy efficiency when they decided to hide their PV meter (A) and invertor (D), and reduce their interaction as a result: *"…lots of people have covered their meters with a blanket, put bookcases in front and around it... So, it is just ugly, not only for me"* (A4).
- *Cost*. The high cost of changing a PV meter or an inverter was the main intermediary obstacle for some occupants in projects A, C and D to not improve their capability to match their energy loads: *"…I did not make any change…I could buy a wireless smart meter or inverter, but the cost will be prohibitive for me"* (A3). Similarly, the cost stopped occupants in project D improving their systems by attaching micro-inverters to each panel, to avoid overshadowing the PV panels by trees.

- *Digital Forums*. Google and group email, as new intermediary, enabled occupants to discuss the possible methods to clean their inaccessible PV panels (D), to identify collective occupants' misunderstanding in relation to the FIT registration process and responsibilities (F), to argue how to achieve the optimum use of the total PV energy that was generating from the all community systems (A) and to identify a collective problem associated with the use of energy monitoring device (A).
- *Ethics*. Occupants' environmental ethics encouraged them in project C to regularly meet and discuss their PV and energy performance which had an impact on managing their energy loads and to suggest technical solutions to do so (C). This had also motivated some occupants to individually monitor their energy efficiency and to manage their energy loads (A, E). By contrast, not having this ethics for some occupants stopped all community members in project B from collectively discussing their energy performance as *"it generated a tension between people who really want to reduce their carbon footprint and people who do not give a very much consideration for that"* (B1).

Human intermediaries

Two existing human intermediaries from the provisioning stage (PO and architect) and three new ones for the occupancy stage (energy supplier, academic researchers, and experts) were identified in all projects.

- *Provisioning Occupant (PO)*. The PO acted as an intermediary in project A when he passed on advice to the other community members not to interact with their PV controls other than take meter readings, assuming that *"people in this project are already low consumers"* (A3) and supposing that all the measures to be a low carbon community was considered in the provisioning stage; as a result, the load matching potential was never examined and discussed.
- *An energy supplier, a researcher* and *an electric car charging point specialist* performed as significant intermediaries in project A in terms of passing on educational advice to the occupants about how to use their energy efficiently in their houses by matching their energy loads and reduce the imported energy from the main grid *"…if I used my things during the day, I actually then keep my bill low. (interviewer: Did the guidance tell you that?) No. Magda did"* (A4). In the same project, the academic researcher also passed on information to some occupants about how to improve their PV performance by keeping the invertor well ventilated. All these perceptions were supposed to be passed on by the PV installer as an intermediary before people moved into their homes.
- *Architect*. The architect of project F, as a continuing intermediary, led a large research program (SENSIBLE) funded by EU to install individual batteries in some houses and a big community battery. On the individual level, the small batteries enabled occupants to individually manage their energy loads, while on the community level, the community battery will support the community energy self-reliant by provide them access to affordable energy in the community by sharing excess electricity generated in their properties with other community members (Rodrigues et al., 2016).

Conclusion

This paper has investigated the emergence and function of various *intermediaries* as an innovative approach to shifting governance and low carbon transition, by linking an ANT-theoretical perspective with Practice theory in relation to PV provision and use, in two different types of housing provision in the UK. PV systems have not been examined in previous studies concerned with the implementation gap of domestic low carbon technologies, particularly in relation to the provision team governance of the system design and integration in homes. ANT shifts the focus away from fixed interest of actors to an explanation of actor networks by which PV design and use are specified and governed. ANT further demonstrates that non-human actors 'make a difference' to the outcomes. Practice theory has helped to address new and continuing intermediaries and the impact of the social and physical context of PV on the co-construction between occupants and PV systems. The innovative combination of these two theories and their distinct methods of data collection and analysis revealed new findings which the individual theories cannot do - the key methodological contribution of this paper. The potential neutral participatory role of POs in terms of improving the system design and reducing the implementation gap in the PC projects was significantly undermined by: 1) the assumptions made by PV professionals in relation to occupants interacting with the system, and 2) the POs having an individual agenda for PV system during the construction process.

The role of POs needs to be redefined in terms of them understanding the meaning of PV technology as a system that has potential to impact on occupant energy use instead of perceiving it as technology that provides green and free electricity. Load matching potentials, therefore, need to be clearly discussed and considered in the PV design stage and to be adequately translated to occupation by the PO during occupation. However, these roles were entirely absent in the NPC projects where the client and main contractor governed the occupants' use through their design. This resulted in occupants remaining ignorant about their PV affordance, competence and maintenance. Uniquely, the study has identified the different intermediaries and mediators that influence the occupants' use of the PV system during occupation, which has not been covered in previous studies.

FIT polices, location and aesthetic values were the key non-human intermediaries in the both provision and use stages. FIT need to be designed to encourage users to match their energy loads rather than simply installing PV systems for financial profit. All PV appliances should be located in visible places for occupants and consideration of aesthetics is an emotional necessity to achieve potential interaction. Collective graphs and digital forums, offered by community housing context, are very powerful intermediaries, which enable occupants to understand and compare their PV and energy performances and identify underperformance problems. These intermediaries are probably missing in NPC projects generally which is a major concern, as they make up the majority of housing in the UK. In general, the human intermediaries helped occupants to match their energy loads, while the non-human intermediaries encouraged occupants to interact with their PV appliances, to identify underperformance problems, and to increase their PV and energy perceptions.

Significantly, none of occupant in all projects referred to Home User Guide (HUG) as an intermediary that has an impact on their system use due to their limited PV information, and provision by the installers. Other new intermediaries need to be introduced by the policymaker in particular for the effective utilisation of new domestic technologies, through practices and processes, and in terms of educating PV occupants how to match their energy loads. Further study is needed to investigate the detailed role of other intermediaries, such as media, public forums and governmental campaigns in improving the PV system use.

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SIPRIUS+: A sustainability monitoring tool specifically designed for urban brownfields regeneration projects

Martine Laprise[1], Sophie Lufkin[1] and Emmanuel Rey[1]

[1] Laboratory of Architecture and Sustainable Technologies (LAST), Institute of Architecture (IA), School of Architecture, Civil and Environmental Engineering (ENAC), Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland, martine.laprise@epfl.ch

Abstract: One of the relevant strategies to limit the sprawl of post-industrial European cities is the regeneration of urban brownfields. This type of projects concentrates new development within already urbanized areas and contributes to their revitalization. Despite this, projects developed on urban brownfields are not automatically sustainable. It is explained by their inherent complex nature, due to the specificities of the site, the project process and the sustainability concept itself. Focusing on these challenges, SIPRIUS+ is an operational monitoring tool using an interdisciplinary approach. It supports a search for global quality, tailored to urban brownfields regeneration projects and integrated into the project dynamics. This new generation tool is a hybrid between a sustainability indicator system adapted to issues raised by brownfield regeneration and a user-friendly, web-based monitoring software. SIPRIUS+ assists practitioners in their decision-making: it facilitates the integration, assessment, and follow-up of sustainability indicators during the transformation of urban brownfields into new environmentally friendly and socially inclusive neighborhoods, respectful of future generations. This paper gives a description of the different steps of the tool's design and an overview of its functionalities. Then, the main features of SIPRIUS+ are presented through a test application on a case study located in Yverdon-les-Bains (Switzerland).

Keywords: Urban Brownfield, Regeneration Projects, Sustainability, Monitoring tool, Decision-making

Introduction

As the negative effects of urban sprawl are now widely recognized, post-industrial European cities must turn to strategic densification (EEA, 2006). In this context, Urban Brownfields Regeneration Projects (UBRP) offer great opportunities to densify and revitalize existing built areas. This type of operation matches the compact and polycentric city model, identified as a relevant vision to make the sustainable city (Rogers and Gumuchdjian, 1998; Williams, 2010). Hence, across Europe, land use policies strongly foster UBRP as a sustainable land take solution (European Comission, 2013). However, "any argument that all brownfields redevelopment is inherently sustainable is unjustified" (Eisen, 1999). Quite often, URBP refers only partially or superficially to the holistic concept of sustainability (Andres and Bochet, 2010; Rey, 2012). In fact, dealing with sustainability objectives asks for the consideration of a multitude of parameters going far beyond the limits of intuition. This adds to the complex nature of UBRP generated by the specificities of the site (neighborhood scale, possible contamination, social stigma, etc.) and the specificities of the project process (multitude of stakeholders, long duration, etc.).

To handle the overall complexity of UBRP, it is essential to act on the basis of sound information and to put a system in place to collect it as appropriate (Pediaditi et al., 2010). Because the integration of sustainability is not automatic, it appears essential to assess regularly, equally and concurrently environmental, social and economic criteria. To be accurate, the assessment must take into account the specificities of UBRP and the national/regional context (Sharifi and Murayama, 2013). Moreover, to pursue sustainability objectives throughout the operation, frequent assessments must be part of the project dynamics (Berardi, 2011). The assessment results should provide elements to support decisions in a way that allows iterative setting of sustainability objectives. To do so, a balance between exhaustive and clear information is needed, provided by an interdisciplinary approach (Bartke and Schwarze, 2015). In short, an operational monitoring tool is required. This tool must satisfy the following three general requirements: (1) a search for global quality; (2) an adequacy with the specificities of UBRP; (3) an integration into the project dynamics (Rey, 2012).

A recent state of the art has reported few evaluation systems adapted to brownfield regeneration, but dissociated from the overall project dynamics; they fail at monitoring sustainability in an operational way (Laprise et al., 2015a). To fill this gap, a research project entitled SIPRIUS+ is currently underway at Ecole Polytechnique Fédérale de Lausanne (EPFL) to propose a new sustainability monitoring tool tailored to UBRP. This innovative research project is based on a hybridization strategy, combining two existing tools from different fields: the built environment and the business management. Following the above theoretical considerations, this paper presents briefly the method behind the creation of the monitoring tool. Then, it describes the main functionalities of SIPRIUS+. Finally, a test application on a case study reveals how SIPRIUS+ can facilitate decision-making during the transformation of urban brownfields into new environmentally friendly and socially inclusive neighborhoods.

Method: hybridization strategy

Even if they do not answer the 3 general requirements, we know that a multitude of multicriteria evaluation tools in the built environment are already available (Sharifi and Murayama, 2013). At the same time, efficient digital monitoring software are used in many diverse fields where the management of sustainability issues is needed (Laprise et al., 2015b). While indicators may differ, the methods used to monitor sustainability in businesses or project development have considerable similarities. In reaction to that, we adopt an approach based on the potential of existing knowledge and expertise. This hybridization strategy is to select an existing monitoring software and combine it with the adequate indicator system.

An extensive analysis led us to the complementary selection of an IT solution, the web-based monitoring software OKpilot, and SIPRIUS, an indicator system specifically designed to integrate sustainability into the dynamics of UBRP (Laprise et al., 2015b). Together, they have the potential to fulfill the 3 general requirements previously described. Here we make a short description of the two tools and we identify the adaptations required before performing the hybridization.

The indicator system SIPRIUS

SIPRIUS measures several quantitative and qualitative sustainability indicators and follows their evolution through the UBRP process (Rey, 2012). The indicators covering environmental, socio-cultural and economic aspects reflect the Swiss context. They are grouped into two categories: Context indicators and Project indicators. To measure and compare each indicator, SIPRIUS attributes four reference values: Limit Value (VL), Average Value (VA), Target Value (VT), and Best Practice Value (VB). Each indicator has its own datasheet containing all the relevant information to perform the assessment (description, evaluation method, measurement unit, reference values, and references). SIPRIUS has proven to be a relevant method to evaluate sustainability. However, SIPRIUS is not operational yet; because it is not integrated into a digital tool, its use on a regular basis depends too much on stakeholder's motivation. Developed in 2006, SIPRIUS needs some adaptations to comply with current practice (Table 1).

The monitoring software OKpilot

OKpilot is a web-based solution designed to help businesses and organizations to comply with different checklists of indicators and to increase their performance (GLOBALITE Management, 2014). The collaborative monitoring software has features that allow an optimal control of projects and activities. In this sense, three main interrelated sections compose OKpilot: Evaluation, Outcomes, and Management. Initially, OKpilot is not adapted to monitor sustainability in the built environment. However, the main advantage of OKpilot is its adaptability; thanks to a clear dissociation between its monitoring functionalities and the assessment database, OKpilot has the potential, providing some adaptations, to answer the needs for an operational monitoring tool adapted to UBRP (Table 1). Most of OKpilot's adaptations involve minor adjustments (1 to 4). Adaptation 5 and 6 require more extensive computer programming. All these adaptations affect the Assessment and Outcome sections; the Management section has useful monitoring features (risk alerts, objective setting, deadlines, internal mail, user configuration, etc.) that are highly functional and already compatible with SIPRIUS. This latter section does not need adaptations.

Table 1. List of the required adaptations for SIPRIUS and OKpilot.

SIPRIUS: required adaptations	**OKpilot: required adaptations**
1. Update of the existing indicators	1. Integration of documents and data sources
	2. Possibility to unselect irrelevant indicators
2. Inclusion of missing indicators	3. Harmonization of terminologies
	4. Organization of OKpilot's tree diagram
3. Creation of a list of Governance indicators	5. Conversion of the reference values
	6. Enhancement of the graphical displays

The making of SIPRIUS+: hybridization process

Regarding SIPRIUS, we have updated 7 indicators to reflect current concerns of the practice, norms and standards evolutions. In all cases, the reference values (VL, VA, VT, and VB) are more restrictive than the ones suggested by the original version of SIPRIUS. For example, indicators C2.2 Global warming potential (GWP) and P2.1 Non-renewable primary energy for construction, renovation and demolition of buildings had no reference values in the first version of SIPRIUS because, at the time, no sufficient comparative calculations or recognized targets were available. Since then, the Swiss recommendation SIA 2040 has been released which encloses objectives for those two indicators (SIA, 2011). For Adaptation 2, we included 4 new indicators following the comparison of SIPRIUS with other indicator systems specifically developed for brownfield regeneration projects and sustainability certifications at the neighborhood scale. *C4.1 Degree of prevention of light emission* is an example of a new indicator completing SIPRIUS. Finally, we created a list of 11 indicators in relation to the governance of UBRP, which aim at evaluating the management and the process of the project. Half of these indicators have a concrete dimension in relation to the realization of the project such as remediation, temporary uses, construction site and commissioning. They are limited in time, to a specific project phase. This does not exclude a regular assessment, starting from the beginning, in order to set objectives. The other half of these indicators relate to all aspects involving the implementation and smooth execution of the UBRP and its sustainability objectives. Participation, collaboration, information access and assessment are part of it. We elaborated this new list while analyzing the literature as well as other indicator and certification systems. In total, after completing these three types of adaptations, SIPRIUS offers 57 indicators.

Regarding OKpilot, we performed Adaptations 1 to 4 in collaboration with the IT team as mentioned in the method. For Adaptation 5, we changed the way indicators are measured from percentages to absolute values, corresponding to SIPRIUS' reference values (VL, VA, VT and VB). In the Evaluation section, a new slider allows assigning a value to each indicator. This section also includes all relevant information and documents to assist the evaluation. In addition, a standard color code has been associated with each reference value: orange corresponds to VL, yellow to VA, light green to VC and dark green to VB. As for red, it corresponds to an indicator whose performance does not reach the limit value (VL). Adaptation 5 implied coding work that had repercussions on the representation of the results (Outcome). Thus, this work was done concurrently with Adaptation 6. The Outcome "Chart", used to show an overview of the results at a given moment, has evolved in order to show all indicators simultaneously. In the previous version, the "Chart" results were showing only aggregated indicators under their corresponding criteria. Furthermore, we added options to customize the visualization according to a selection of indicators, sustainability aspects or value (Figure 3). The graphical display entitled "Evolution" is a completely new feature of OKpilot, essential to monitor UBRP. It shows the evolution of a given indicator from the objective or initial situation to the expected final situation, including the current situation (Figure 4). It has the same options as the "Chart", plus the option to show a summary of the repartition of several indicators, according to their performance (Figure 5).

Once the adaptations completed, the two tools are ready to merge as one new hybrid operational monitoring tool. Entitled SIPRIUS+, it brings together the evaluation data of more than 50 sustainability indicators and offers several ways to communicate their results. Moreover, SIPRIUS+ has useful functionalities in order to manage them in an interdisciplinary and collaborative way (allocation and follow-up of indicators, alerts or objectives setting, reporting, risk identification, etc.). In other words, it gives a shared vision of sustainability and an important decision-making support to the UBRP key stakeholders. To finalize the hybridization process, we designed for SIPRIUS+ a new customizable homepage including a simplified menu. Figure 1 shows this homepage as an introduction to the test application.

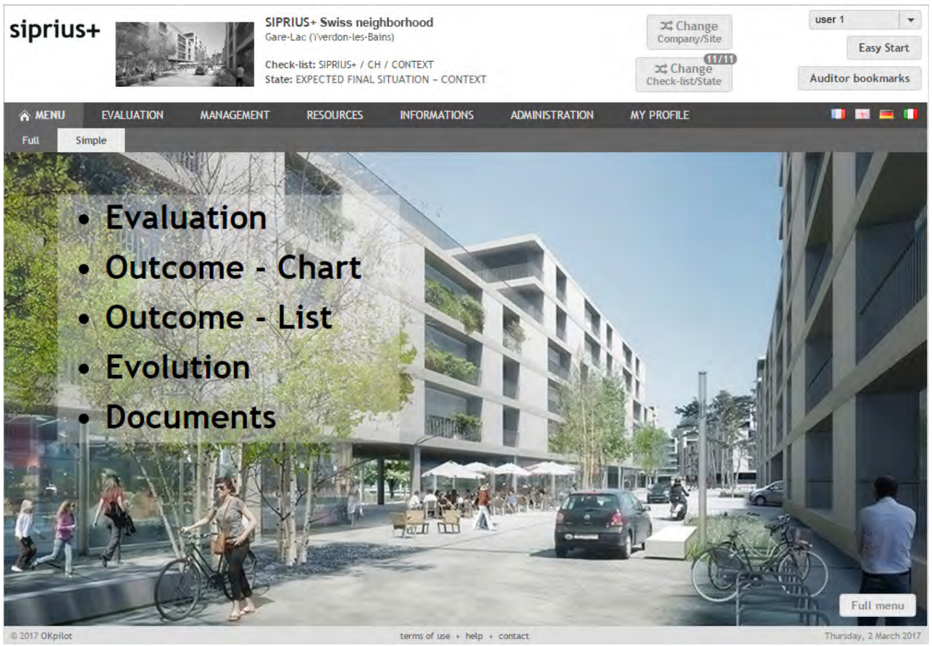

Figure 1. A screenshot of SIPRIUS+'s homepage customized for the Gare-Lac case study.

Test application

For the test application, we selected a case study representative of UBRP, with the strong intention of including sustainability in order to evaluate a maximum of indicators. Indeed, the underlying aim of the test application is to verify the usability of SIPRIUS+ and to make iterative settings on the tool. Known as the Gare-Lac neighborhood, the chosen case study is located on a 23 ha disused industrial area. It is close to the center of Yverdon-les-Bains (Switzerland) but remains disconnected by railways. The master plan (Figure 2), developed by a multidisciplinary team, was officially adopted in 2015 (URBAT et al., 2012). It consists of a new mixed-use neighborhood (3810 inhabitants + 1260 jobs) with open courtyard buildings, which put emphasis on an optimal density thanks to green and public spaces, soft mobility networks, eco-friendly construction and good access to services and public amenities. This new master plan will now be assessed with SIPRIUS+.

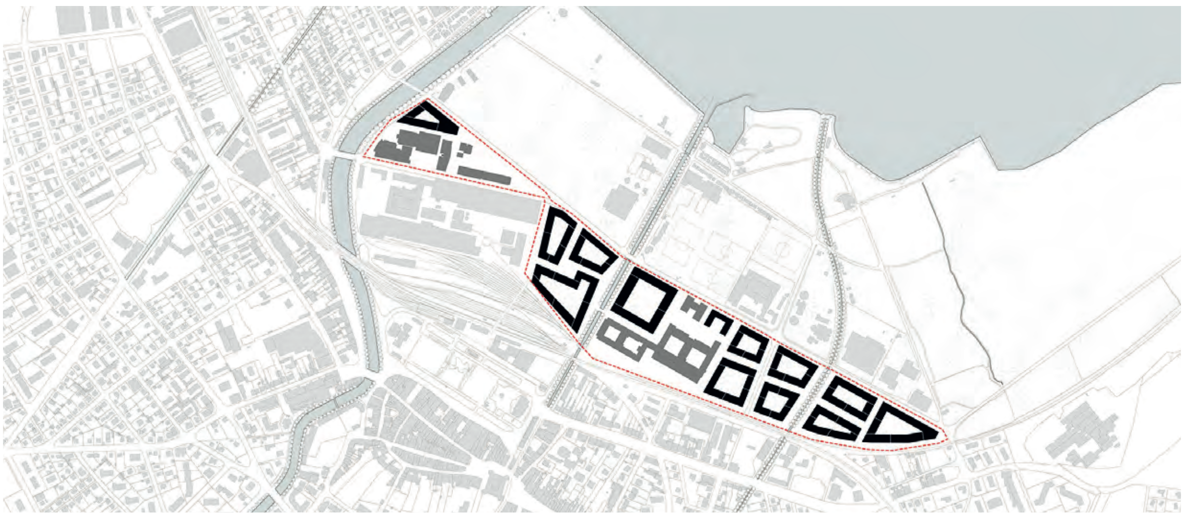

Figure 2. Master plan of the Gare-Lac neighborhood in Yverdon-les-Bains (Switzerland). In dark gray, existing buildings (to be retrofitted), in black future buildings.

Results

The test application has resulted in a detailed evaluation report. It includes a description of the process and case study, a description of each indicator results along with the "Evolution" graphical display, a global view of the results for each type of indicators (Context, Project and Governance) at different situations (initial, current ,and expected final situation), and a summary of the results for the Gare-Lac neighborhood. In addition, the report provides also the datasheets of all the indicators. We extracted all these data from SIPRIUS+. We show here a brief example of the Context indicators results.

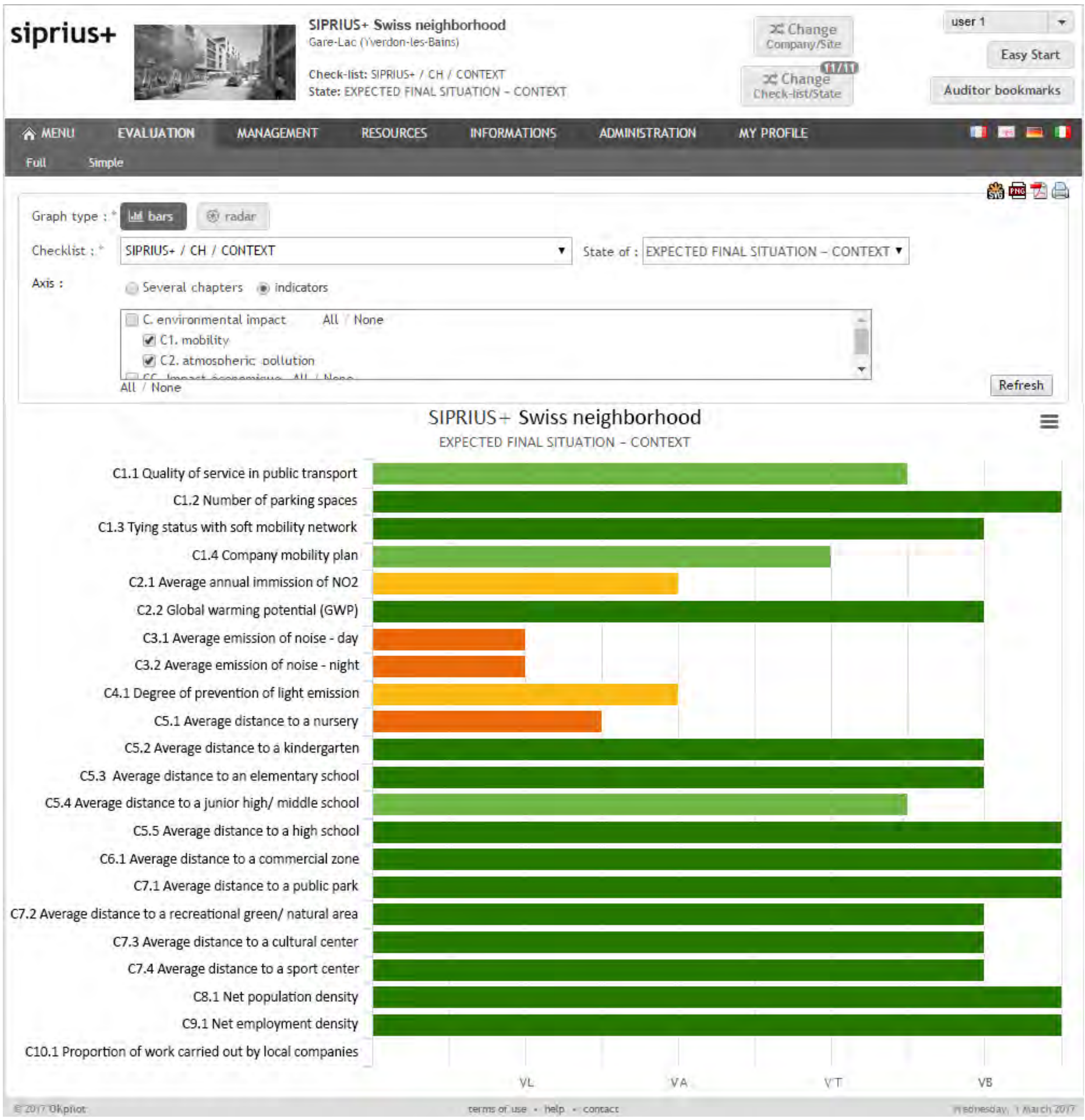

Figure 3. Outcome "Chart" extracted from SIPRIUS+ showing the results of the expected final situation for Context indicators

The "Chart" (Figure 3) gives an overview of the expected final situation of the Gare-Lac neighborhood, that is to say, the foreseeable values at the end of the UBRP. In general, we notice a high performance, reaching the Best Practice Value (VB) for most of the Context indicators. This is mainly explained by the fact that the evaluation is based on the master plan.

Because the integration of sustainability has more chances of success at the beginning of a project process, setting high objectives in the master plan is important. Nevertheless, this evaluation is not static; the results are likely to change over time, following the evolution of the project. This consideration is embedded in the monitoring concept. Otherwise, one can also notice by looking at the "Chart" that some indicators are at the Limit Value (VL) or Average Value (VA), i.e. orange and yellow. At this stage of the project, it highlights aspects that need particular attention in order to reach high performance in terms of sustainability. Going more into details with the graphical display "Evolution" (Figure 4), stakeholders can follow one by one the progression of different indicators, through all the UBRP process. Management features linked to each indicator, such as risk alerts and objective settings, can assist SIPRIUS+ users as the project changes. Finally, SIPRIUS+ offers a summary of the sustainability performance of the Gare-Lac neighborhood (Figure 5). This summary also gives insights on the global performances of Context, Project and Governance indicators.

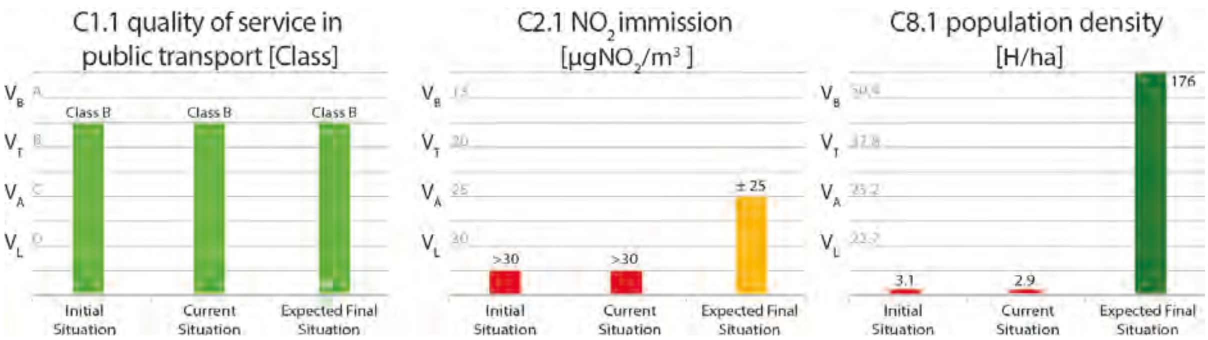

Figure 4. Evolution graphical displays extracted from SIPRIUS+ for three examples of Context indicators

This test application shows that SIPRIUS+ can provide an exhaustive picture of the sustainability status of an UBRP at a given moment, in this case, the Gare-Lac neighborhood. Altogether, SIPRIUS+' Outputs and Management features can contribute to following closely the evolution of sustainability objectives throughout the UBRP, which in turn helps to make informed decisions and to share a common vision of the future neighborhood with professional stakeholders as well as the concerned communities.

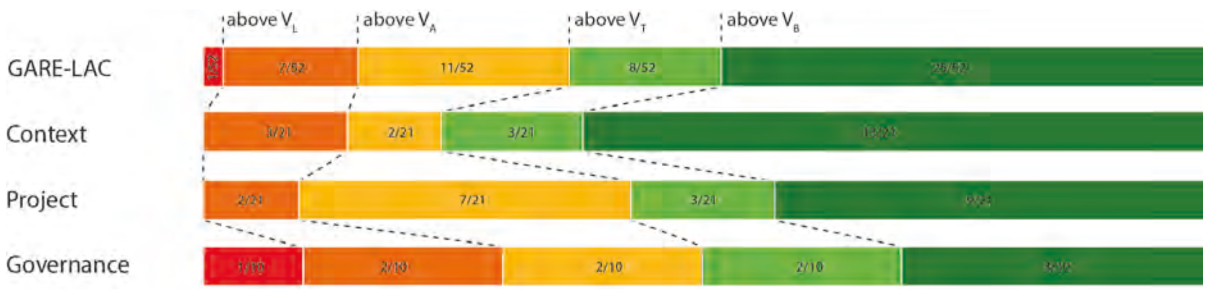

Figure 5. Repartition of sustainability indicators performance for the Gare-Lac neighborhood.

Conclusion

Urban Brownfields Regeneration Projects (UBRP) are not inherently sustainable. Consequently, this research project proposes an operational monitoring tool facilitating the transformation of urban brownfields into tomorrow's sustainable neighborhoods. Entitled SIPRIUS+, this new generation tool is a hybrid between SIPRIUS, a sustainability indicator

system adapted to brownfield regenerations and OKpilot, a user-friendly, web-based monitoring software. To combine SIPRIUS and OKpilot, some adaptations were first required. Then, we conducted a test application on a case study: the Gare-Lac neighborhood in Yverdon-les-Bains (Switzerland). It shows that SIPRIUS+ can offer a comprehensive picture of the sustainability performance of an UBRP. As a collaborative monitoring tool, SIPRIUS+ can facilitate decision-making regarding sustainability objective thanks to a long-term vision of multiple environmental, social, economic and governance indicators.
However, knowing that these operations sprawl over more a decade, it is not reasonably possible to verify how SIPRIUS+ can truly be integrated into a project dynamics. Thus, further experimentation implies interactive workshops with involved stakeholders of the case study to present SIPRIUS+ and the results. The intention will be to gather their opinion about the potential integration and added value of SIPRIUS+ in the long run within an UBRP team. These activities will be the subject of further publications.

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Thriving in the Slums: Progressive Development and Empowerment of the Urban Poor to Achieve Secure Tenure in the Philippines

Isidoro Malaque III[1,2], Katharine Bartsch[2] and Peter Scriver[2]

[1] Department of Architecture, College of Humanities and Social Sciences, University of the Philippines Mindanao, Davao City, Philippines, irmalaqueiii@up.edu.ph;
[2] School of Architecture and Built Environment, The University of Adelaide, Adelaide, Australia, isidoroiii.malaque, katharine.bartsch, peter.scriver@adelaide.edu.au

Abstract: Thriving cities are characterised by vigorous growth and concepts of flourishing, healthy communities. However, these concepts are not immediately connected with the living conditions in squatter settlements in developing countries. With a rapidly increasing urban population, slum dwellers in developing countries continue to occupy a vulnerable position in urban areas with fear of eviction and displacement from their livelihood. Acknowledging a range of approaches to house slum dwellers, including problematic efforts to relocate inhabitants from a squatter settlement to a regular housing market in a single step, this paper examines the circumstances which have enabled squatter settlers to achieve legal tenure and to build homes, incrementally, that are eventually compliant with the building code. Based on detailed analysis of individual homes and interviews with householders, this paper presents the findings of a comprehensive study of slum settlements in Davao City, Philippines. The progressive development of urban settlements is analysed in the context of Filipino pro-people policies, which have prioritised the rights of the urban poor and empowered them to build low income housing, enabling them to develop sustainable, secure, thriving urban settlements which are the foundation for a better future.

Keywords: Housing policy, Philippines, progressive development, secure tenure, urban poor

Introduction

Thriving cities are characterised by success and prosperity as well as vigorous growth and concepts of flourishing, vibrant, healthy communities. However, these positive themes are not immediately connected with the urban living conditions of slum dwellers in developing countries. The world's population is becoming increasingly urban, and the rapid increase is found in cities of developing countries. In 2015, the United Nations declared that 54% of the world's population lives in urban areas. While it is estimated that the figure will reach 66% by 2050, nearly 90% of this increase will be in Asia and Africa (United Nations, 2015). In this context of unprecedented urbanisation coupled with widespread urban poverty, squatting is often the only means to access affordable shelter for the urban poor. Moreover, slum dwellers in developing countries continue to occupy a vulnerable position in urban areas with fear of eviction and displacement from their livelihood. Squatter settlements are often seen as indicators of disease in a healthy city because of their perceived negative impact on the urban and ecological environment (Appadurai, 2000), as McFarlane contends 'informal settlements…remain populations outside the sphere of citizenship and notions of the clean, ordered modern city' (2008, p. 1). On the other hand, the development of informal housing often provides an immediate solution to shelter needs of the urban poor who migrate to the city in search of a better livelihood. The recognition of self-help housing in informal environments has its roots in the 1960s evident in the work of Abrams (1964) acknowledging the role of squatters in the urbanizing world; and, in the seminal work of Turner (1968) derived from his involvement in the squatter settlements of Lima, Peru. Furthermore, in the 1970s, Ward (1976) explored squatter settlements in Mexico as a low-income housing solution. This process continues in the developing world, documented in the ongoing work of Mitlin and Satterthwaite (2004), Mukhija (2003), and others. Moreover, increasingly positive attitudes toward squatter settlements are expressed by UN-HABITAT (2008) in their case for a 'slum of hope' (in contrast to 'slums of despair' where formerly well-developed urban districts have deteriorated due to regressive economic and social activities).

Acknowledging that housing is a basic human right, governments are committed to provide shelter for the low-income sector of their respective countries. However, housing policy and programmes in developing countries, like the Philippines, are often based on models (applied with varying degrees of success) which originate in high-income countries. Defined by Lim (1987) as a 'one-step regularization model', this model is intended to relocate the urban poor from a squatter settlement to a regular housing market in a single step. Alternatively, it is also characterized as 'instant development' (Turner, 1967); or, a 'product approach' where a complete housing package is delivered through a sophisticated system in the housing market (Ferguson and Navarrete, 2003). In the Philippines, an example of this traditional approach was a major housing programme under the Marcos regime known as the *Bagong Lipunan* Improvement of Sites and Services (BLISS) conceived in the late 1970s. Intended as housing for the poor, many BLISS housing projects were completed in Metro Manila in 1983 as discussed by Abueg (1986). However, the buildings were similar to other condominiums catering to higher income earners that did not seem to match the affordability of the urban poor.

Decentralized housing and urban policies under the Marcos regime in the Philippines ended with the People Power Revolution in 1986. Consequently, the new 1987 Philippine Constitution served as a general framework for new governance which took an explicit stand on issues related to the alleviation of urban poverty. It established guiding principles on the conditions of eviction and the roles of the government, private and non-profit organizations in housing delivery and infrastructure development (Shatkin, 2007). The new Constitution became the basis for two major pieces of legislation pertinent to informal settlement, namely, the Local Government Code of 1991 and the Urban Development and Housing Act of 1992, which, according to Porio and Crisol (2004, p. 208), 'marked the departure from eviction and relocation to the adoption of a more decentralized approach towards housing and urban development'. Furthermore, these policies also integrated the participation of the urban poor in land use planning and redefined the roles of government agencies, urban poor communities and mediating groups such as NGOs. As such, they changed the performance and relationships of stakeholders in the housing sector (Porio and Crisol, 2004). Given these developments, there is a need to discuss the progressive form of urban development in relation to these recent housing and urban policies in the Philippines.

Background, aims and objectives of this paper

This paper maintains that the progressive development of urban settlements coincides with the legalisation of land tenure, and the incremental construction of housing units and improvements to sites and services. Preliminarily, this argument is informed by detailed observation of how an informal settlement in Davao City, Philippines, underwent a transformation from an informal settlement to a more formal one (Malaque III, 2013). In a subsequent comprehensive study of 74 households in 11 settlements, in the same city, the following housing phenomena were observed based on detailed interviews with residents and *in situ* building analysis. Firstly, it was deduced that urban households can be classified into five different types in a range of contiguous categories from formal (Type I) to informal (Type V) housing, and it was observed how householders moved from one type to another until they became owners of formal housing (defined as legal tenure with construction compliant with the building code). Characterised as a multi-step transition process, one way to achieve formal housing occurred when an informal housing unit in a progressive urban settlement was upgraded to become a formal housing unit in the same location (Malaque III et al, 2014). Secondly, further examination of the phenomenon revealed that the incremental construction of housing units in a progressive urban development was a direct result of the improvement of the householder's security of tenure. This was exemplified when an informal housing unit was upgraded with better building materials and standard methods of construction when the inhabitant's degree of legal and financial security improved. Over time, it was observed that the physical condition of the house could deteriorate over time while the inhabitants focused on payment for land. However, upon achievement of legal ownership of land, the house was further refurbished to become a formal structure (Malaque III et al, 2015). Thirdly, an evolution of housing is modelled by connecting the incremental constructions of housing cases representing the range of housing types from informal to formal. This illustrated the evolution of housing from a simple shack in a squatter settlement to become permanent formal architecture; these structures comprised one- and two-storey residential buildings during the course of their development (Malaque III et al, 2015).

Despite being the subject of comprehensive scholarship, this dynamic phenomenon of housing and urban development requires further understanding to inform more effective urban planning interventions which are both appropriate and sustainable in developing countries. Thus, to further understand this dynamic phenomenon in the case of a city in a developing country, the aim of this paper is to illustrate the progressive development of this type of urban settlement. This physical phenomenon is discussed in the context of pro-people housing and urban policies, empowering the poor and enabling them to develop sustainable, secure, thriving low-income urban settlements.

The study area

The comprehensive study was conducted in Davao City, Philippines, located a thousand kilometres south of Manila. This is the same study area presented in previous papers (Malaque III, 2013; Malaque III et al, 2014; 2015; 2016). Recently, the Philippine population based on the 2015 census was 100.98 million, reported by the Philippine Statistics Authority (PSA). In 2012, the population of Davao City was 1.45 million. It has increased significantly to 1.63 million based on the 2015 census (Philippine Statistics Authority, 2016). Davao City is the only city outside the National Capital Region, also known as Metro Manila, that has a population of more than one million. Housing provision in the low-income sector is one of the major issues in the context of local urban development in Davao City which is populated by impoverished rural immigrants who have settled in precarious informal settlements. While this pattern of mobility repeats trends throughout the developing world, the continued escalation of this pattern prompts the need for this continued scholarship in housing research.

Methodology

The data, identified in previous papers (Malaque III et al, 2014; 2015; 2016), was collected from February to April 2014, in accordance with fieldwork protocols approved by The University of Adelaide Human Research Ethics Committee (January 2014). This same data informs this paper. Access to a total of 74 households in 11 settlements, and the selection of settlements and representative household cases were discussed more thoroughly in a previous paper (Malaque III et al, 2014). In subsequent case analyses, previous papers explored the incremental housing construction (Malaque III et al, 2015), and the evolution of housing (Malaque III et al, 2016), of a representative sub-set of 16 of the 74 household cases. For this purpose of studying the phenomenon of progressive development of urban settlements, the analysis focused on 58 housing cases situated in seven progressive settlements. Contrary to planned settlements, progressive settlements are those which were inhabited by informal settlers who then became recipients of land tenure assistance from the government, or processed negotiation for purchase of their squatter land from the legal land owner, which are assumed to develop continuously over time. Contrary to observing the progressive development of a single urban settlement in a long span of time, from its informal formation towards attaining formal status, the cases presented in this study serve as snapshots of varying housing and settlement status taken at one time in 2014. The progressive development of urban settlements is analysed by counting on the number of housing cases respective to each housing type per settlement. This revealed the status of settlements and their position in the multi-step transition from informal to formal status. Hence, counting and mapping the housing cases respective to different housing types in each settlement, as shown in Figure 1, animates the dynamic progressive development of urban settlements. Finally, the result is discussed in the context of recent developments in housing and urban policies in the Philippines.

Result: the progressive development of urban settlements

The progressive development of urban settlements began with the formation of informal settlements. The settlement sites where 'informal' (Type V) housing is located, are characterised with undeveloped sites which lack basic services. In this study, it is evident in the Arroyo Compound and the Kobbler settlement sites. In the same informal settlements, the 'in-transition informal' (Type IV) housing types are located. With the same physical characteristics, the difference between the two housing types is that the householders of the latter are in the process of organising themselves to initiate improvement of land tenure, thus labelled as 'in-transition informal'.

The organisation of informal householders played an important role in the progressive development of their settlements. Among other requirements, the organisation must be legally accredited by an appropriate agency, such as the Presidential Commission for the Urban Poor, to be eligible for the government programme. In this study, there were two settlement cases which were identified as 'in-transition' (Type IV) housing. These included the Peace Avenue and Green Prairie Homes settlement sites which were beneficiaries of a Land Tenure Assistance Programme (LTAP) implemented by the National Housing Authority (NHA). The former is an example of 'on-site' project implementation while the latter is an example of 'off-site' LTAP project implementations. For the 'on-site' project in Peace Avenue, the progressive development of sites and services is starting to be noticed. The irregularity of the allotments reflects its initial formation as a squatter site. The inhabitants of these settlements recently subscribed to the government programme in 2000, which helped them to gain a small increase in their security. With a long way to pay for the land to own legal titles, at the moment, they are still holding some fear of eviction at any point in time if they fail to continuously pay for the land.

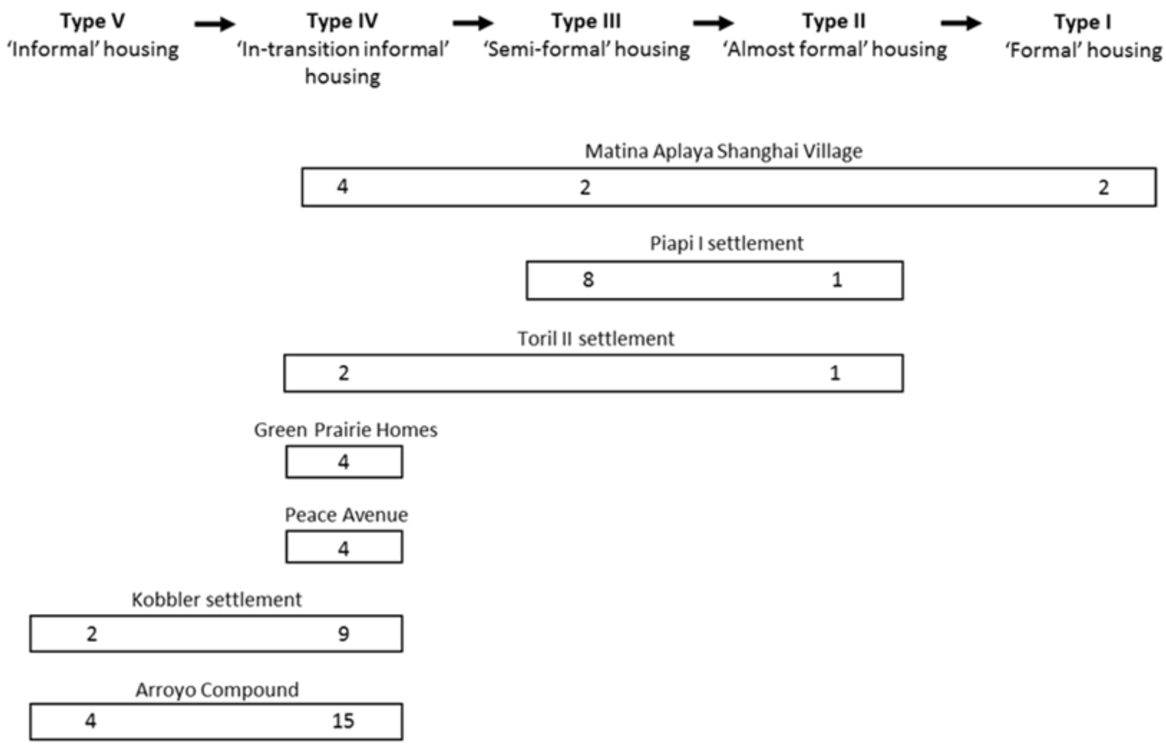

Figure 1. Progressive development of urban settlements.

The urban settlements covered by this study, with inhabitants who had been beneficiaries of government assistance for land tenure, had progressively developed towards a more formal status. For example, the inhabitants of Toril II settlement had been recipients of sites and services implemented by the NHA since 1988. As far as this study is concerned, two out three household cases are in 'in-transition' (Type IV) housing while the other one already progressed to an 'almost formal' (Type II) housing. On the other hand, the Matina Aplaya Shanghai Village, with inhabitants who had been recipients of the Community Mortgage Programme (CMP) since 1993, progressed further with varied housing types from 'in-transition informal' (Type IV) to 'formal' (Type I) as shown in Figure 1. Four out of eight household cases currently occupy 'in-transition informal' (Type IV) housing; two are in 'semi-formal' (Type III) housing; and, two are in 'formal' (Type I) housing. These settlement sites were former squatter areas which progressively developed in-situ, mainly because of government assistance for the formalisation of land tenure. In the case of these two settlements, the government programmes being implemented were the sites and services and the CMP, respectively.

The earlier the implementation of tenure assistance from the government, the greater the urban settlement progressed. For example, in the case of the Piapi I settlement, its inhabitants had been recipients of a slum upgrading programme implemented by the NHA after 1981. Currently, eight out of nine of its household cases examined in this study were classified as 'semi-formal' (Type III) housing as shown in Figure 1. The Piapi I settlement is more advanced compared to the Toril II and the Matina Aplaya Shanghai Village settlements, with beneficiaries of land tenure assistance by the government in the later dates. Most of the household cases in the Toril II and the Matina Aplaya Shanghai Village settlements were in 'in-transition' (Type IV) housing, which were behind in comparison with cases in the Piapi I settlement because their respective government programmes were implemented later, in 1988 and in 1993. With reference to the discussion on 'incremental construction' of urban poor housing (Malaque et al, 2015), the Piapi I settlement is mostly characterised by 'semi-formal' (Type III) housing, and physically appears as a slum with building structures that have become dilapidated over time. This is because the inhabitants are prioritising their investment in the improvement of land tenure rather than the incremental construction of their houses. It was noted that once the inhabitants gained better security, the formalisation of housing structures followed. The ultimate form of tenure security was ownership of the legal land title. However, in some cases, full security was also attained by continuous payments for the purchase of land through stable land tenure assistance programmes such as the CMP. This is the case of the Nacorda and the Rafales households in Matina Aplaya Shanghai Village. Despite the fact, that the beneficiaries were in the process of paying for the purchase of their land, their confidence to pay in full and to own legal titles in due course encouraged them to refurbish their houses in accordance with the national building code. Thus, these households were classified as 'formal' (Type I) housing which marks the end goal of progressive urban settlements characterised by formal status in terms of land tenure and housing construction

Discussion

The progressive development of an urban settlement, in the case of Davao City, Philippines, was first explored in a preliminary case study conducted in the Kobbler settlement (Malaque III, 2013). The case of the Kobbler settlement coincides with the observations by Burgess (1985) that are based on genetic principles, whereby an 'illegal' settlement will eventually transform to become a 'pirate' settlement when homeowners organise themselves to improve their tenure. This means an initial impetus to achieve legal settlement status in due course. Furthermore, the comprehensive study of 74 households in 11 settlements, which was informed by rigorous fieldwork, demonstrated a multi-step transition process in the provision of housing for the urban poor (Malaque et al, 2014). Focusing on housing cases in progressive settlements, subsequent case analyses have demonstrated an incremental construction process of housing units in relation to the degree of tenure security (Malaque et al, 2015); and, an evolution of housing whereby a simple shack eventually evolves to become formal architecture that complies with the building code when legal tenure is achieved (Malaque et al, 2016). This study, focusing on 58 housing cases in seven progressive settlements, demonstrated the complete pattern of progressive development of urban settlements from informal to formal status. These parallel observations are not actually new. For example, based on critique towards 'instant development', Turner (1967) alternatively viewed low-income housing provision in developing countries as 'progressive development'; and, in his critique of a 'one-step regularisation model', Lim (1987) alternatively posited the 'multi-step transition model'. What makes the findings of this study unique is that this current phenomenon, observed in this case of Davao City, emerges in relation to, and enhanced by, specific developments in housing policy in the Philippines, and with the urban poor's proactive response to government intervention.

In the context of a pro-poor urban development and housing policy championed in the Philippines, and the localised implementation of development programmes, the urban poor speculates to live in informal settlements, with the aspiration to own a house and a lot of their own, for which they can attain legal tenure in the course of progressive development. Although informal housing in squatter settlements has long been viewed in a negative sense within traditional paradigms of architecture and urban planning, this study shows it must be viewed, instead, as the most affordable and accessible type of shelter for the urban poor. Importantly, the comprehensive study reveals that informal housing is often the first step in a multi-step transition process which precedes incremental construction, the evolution of permanent housing, and the progressive development of settlements. Thus, this study supports the emerging view towards squatter settlement as 'slum of hope' that needs to be better understood such that more appropriate policies and interventions can be applied in the provision of, or support for, low-income housing.

Conclusion

It is noted that the Philippine government, in its recent housing policy approach, moved away from being a provider to focus on its responsibility as a regulatory body. This recent trend in policy making has widened to be more inclusive of the participation of all agencies in housing provision, most importantly the institutional role of NGOs in empowering communities at a grassroots level. Consequently, in the context of informal urbanisation, the urban poor as key stakeholders and beneficiaries, can be recognised as the main producer of the built environment. Accordingly, with the shift in the role of the government as a regulator, housing provision is now centred on the people who have the capacity to build and to provide their own shelter. These recent policy developments in the Philippines have prioritised the rights of the urban poor and empowered them to build low income housing, enabling them to develop sustainable, secure, thriving urban settlements which are the foundation for a better future. Thus, this explains and relates to the progressive form of urban development. In the twenty-first century when the world's population is becoming urban, Filipino pro-poor policies which place more value on the role of the people in housing provision and the formation of the built environment are much needed, most especially in developing countries which are rich in human resources.

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Design to Thrive

A Decade Analysis of Transitioning Residential LEED Communities in the United States

Tarek Rakha[1], Dongmin Shin[1] and Todd W. Moss[2]

[1] School of Architecture, Syracuse University, Syracuse NY, USA

[2] Whitman School of Management, Syracuse University, Syracuse NY, USA

Abstract: Third-party verification and certification processes for low energy built environments have played a critical role in influencing transitioning communities to reduce their emissions footprint in both residential and commercial buildings. One prominent example is the Leadership in Energy and Environmental Design (LEED) certification program, which was conceived by the United States Green Building Council (USGBC). Its residential platform, LEED for Homes, started as a pilot in 2004 and was fully implemented in 2008. This paper attempts to answer the question: what are the characteristics of growing communities for United States LEED residential buildings? The paper examines residential LEED market adoption trends in the United States by analysing a decade-worth of data from 2004 to 2015 (71438 certified units). The study implemented data visualization techniques and statistical analyses to explore predictors of residential LEED community adoption trends. The investigation concluded that market share was associated with educational attainment and number of applied policies, but was not associated with median household income or political orientation (democrat vs. republican). The findings suggest further research is warranted, specifically as related to local practice support from LEED Accredited Professionals as mechanisms of growing transitioning low carbon communities, as well as local level green market incentivization policies.

Keywords: Certification, LEED for Homes, Market Adoption, Policy, Low Carbon Communities

Introduction – LEED for Homes

Minimum standards of construction practice are typically governed through building codes and regulations. However, third-party green building rating systems have played a critical role in influencing communities to transition to lower carbon buildings and neighbourhoods, through possible incentivized recognition (Prum et al, 2009). An example of such rating systems is the Leadership in Energy and Environmental Design (LEED) certification program. LEED was created by the United States Green Building Council (USGBC). The USGBC was founded in 1993, but the LEED program did not start until the early 2000s. Since then, there have been many changes to the certification process, and different categories of certification have been created. The nine main ones are LEED for New Construction, Core & Shell, Schools, Retail, Healthcare, Commercial Interiors, Existing Buildings, Neighbourhood Development, and Homes, the focus of this paper. LEED for Homes started as a pilot in 2004, and was fully implemented in 2008 (Reposa, 2009).

Multiple residential LEED studies were investigated in the literature focusing on case studies (Thomson, 2010), performative aspects (Xiong et al, 2015) and financial analysis (Glossner et al, 2015). However, a gap in the literature exists when investigating comprehensive long-term trends specific to transitioning residential LEED communities.

This paper examines residential LEED market adoption trends in the United States by analysing a decade-worth of data from 2005 to 2014 (71,438 certified units). The study implemented data visualization techniques and statistical analyses to explore the predictors of residential LEED community adoption trends. The paper details the research methodology and analysis procedures, presents findings focused on examined population demographics, implemented green building policies as well as political background, and discusses the findings in the context of potentials, limitations and further research to be pursued. The paper concludes by noting the characteristics of residential LEED communities, and outlines recommendations for relevant transitioning of community practices.

Methodology – Database and Analysis Procedures

In order to examine decade-long trends, a comprehensive database was constructed and analysed using data visualisation techniques and statistical evaluation (Figure 1).

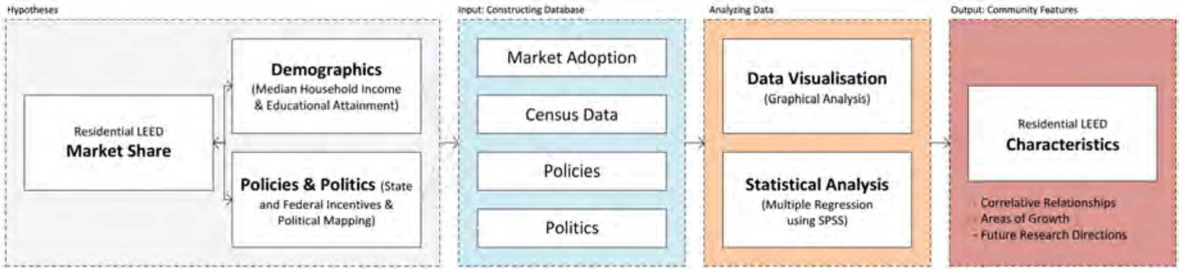

Figure 1. Research Methodology.

Hypotheses

This paper attempts to answer the question: what are the characteristics of growing communities for United States LEED residential buildings? The study was initiated by investigating two hypotheses: we expect to observe a relationship between residential LEED market adoption trends and 1) community demographics, pertaining to household income and levels of education and 2) community policies and politics, focusing on the number of policies that incentivize energy efficiency and adoption of renewable energy, as well as the political orientation of the state. The experiment, therefore, applied the forthcoming analysis techniques to a developed database, with the aim of investigating hypothesized relationships.

Database building

We constructed a database that encompasses the following:

LEED residential market adoption characteristics (2005-2014)
Publically available data for all LEED projects was exported from the USGBC website for all 50 states and Washington D.C. This included project IDs, location, owner, area, registration and certification details. Data was filtered to include only residential building types certified between 2005 and 2014. However, the LEED for Homes certification program started in the year 2008, and residential LEED projects continued under that designation or under a general LEED residential label. Therefore, the database comprised both LEED for Homes and residential LEED projects in that time period (U.S. Green Building Council, 2016).

US census data
The American Fact Finder from the United States Census Bureau website was used to collect all census data for the same time period (US Census Bureau, 2016)., except for the year 2014, where the American Community Survey (ACS) 1-year estimates were used (US Census Bureau,

2014). The database included median household income, population, number of housing units and households, as well as “educational attainment” tabulated for 18 years old and over, where “respondents are classified according to the highest degree or the highest level of school completed. The question included instructions for persons currently enrolled in school to report the level of the previous grade attended or the highest degree received.”

State incentives for renewable and efficiency
The dataset on sustainable technology incentive programs was collected from the Database of State Incentives for Renewables & Efficiency (DSIRE). The website enumerates policies and incentives on both the federal and state level for each state. The sum of policies and incentives was calculated accordingly, and attributed to each state individually (DSIRE, 2016).

Political orientation mapping
A political map was recorded for each state and DC based on the Presidential Election Map from the years 2004, 2008, and 2012. In order to fill the gaps between election years, we assumed that years where no election occurred followed the previous, most recent election map (e.g. 2005 to 2007 followed 2004). The mapping was binary, represented in red states and blue states form, following Republican dominant and Democrat dominant, respectively (Federal Election Commission, 2016).

Analysis techniques

To test the hypotheses using the database, two primary analysis methods were applied:

Data visualisation
A tabulation of the database on Google Sheets enabled in-depth analysis using “Motion” Bubble Charts (Mulrow, 2002). This is an interactive graphical tool that enables five-dimensional investigation charts using the x-axis, y-axis, size and colour of data points, as well as a timeline that animates data for every year, with possible trend trails for each data point across the years. In cases where further examination is needed, we constructed visual representations of data as graphical means of analysis.

Statistical analysis
Multiple regression analysis was applied to the database, where the dependent variable was LEED residential market share in each state. This is calculated as the number of certified LEED residential units divided by number of total residential units. Predictor variables were median household income, educational attainment, total number of policies and political orientation. Regressions reported beta coefficients and significance using the Statistical Package for the Social Science (SPSS) software.

Results – Demographical and Political Trends

The outcomes are predictors that are focused on two topics: community characteristics, as well as their energy efficiency incentivization and political orientation.

Median household income and educational attainment

Multiple regression analysis showed that educational attainment was a significant predictor of LEED residential market share (□= 0.415, $p < 0.001$). Median household income showed a significant but comparably weaker relationship with LEED residential market share (□= □0.085, $p < 0.003$). The motion bubble chart was used to visualise the finding (Figure 2).

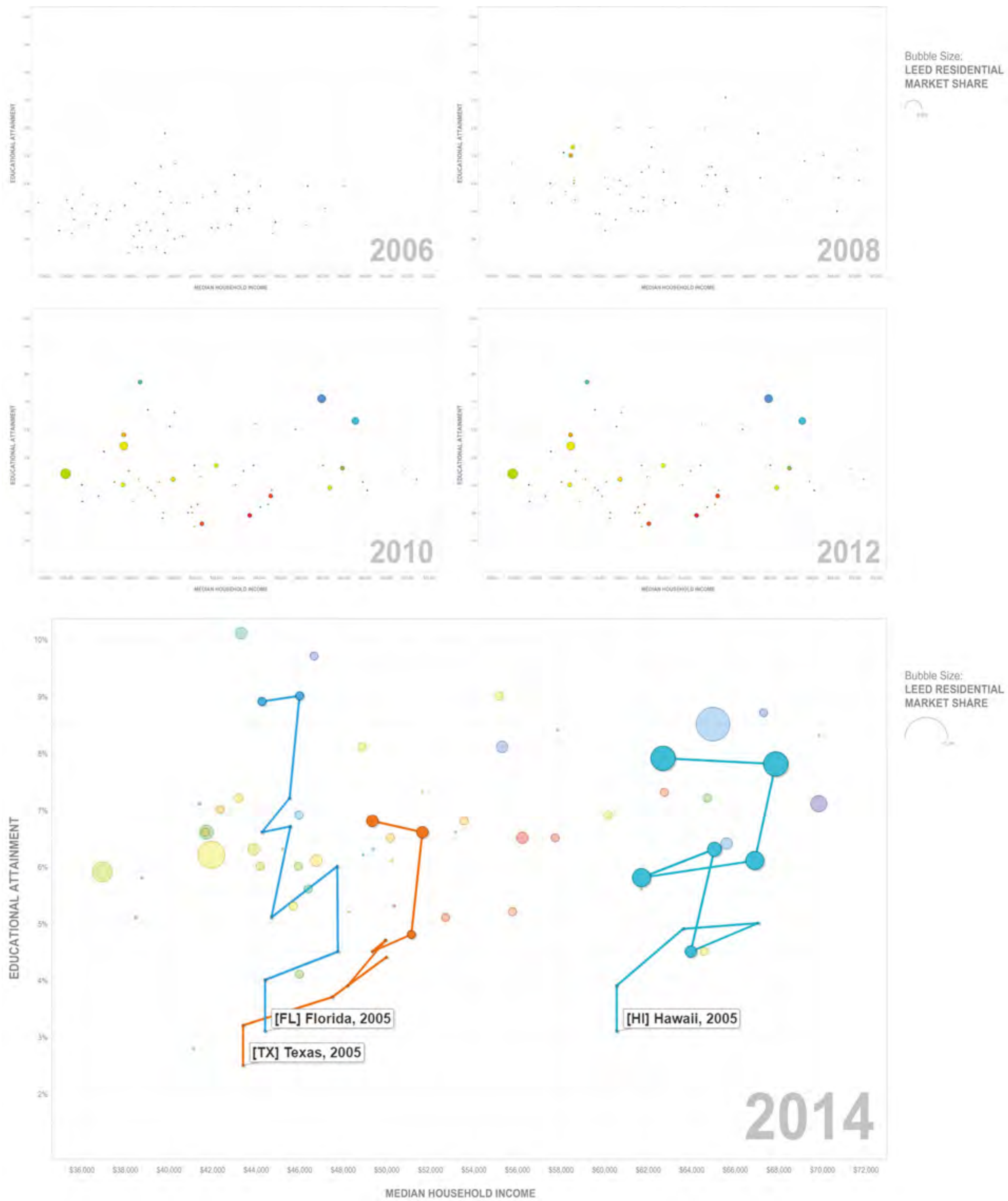

Figure 2. Decade-long motion bubble chart for median household income and educational attainment and LEED residential market share. We observe that data point size increases when moving upwards in time (educational attainment increases). When it moves horizontally (median household income increases), there is little size change. FL, TX, and HI were chosen to demonstrate the trends that correlate with this observation.

Incentivization policies and political orientation

In a multiple regression model including LEED residential market share as the dependent variable, no significant relationships were found when number of incentivization policies (□= -0.112, p< 0.075) and political orientation (□= 0.043, p< 0.015) were the predictor variables. We used graphical analysis as a means of identifying outliers in the data, and we identified cases where number of supporting policies were exaggerated, or cases where the market share was inflated (Figure 3). The bar graph format visualises trends, where gradation becomes significantly darker when number of policies or density of market share is unusually high. When outliers were removed, a test of correlation showed that the number of applied policies were highly correlated, and weaker support was found with political orientation (democrat vs. republican) (Figure 4 and Table 1).

Figure 3. Data visualization of policies/incentives and political map for LEED residential market share.

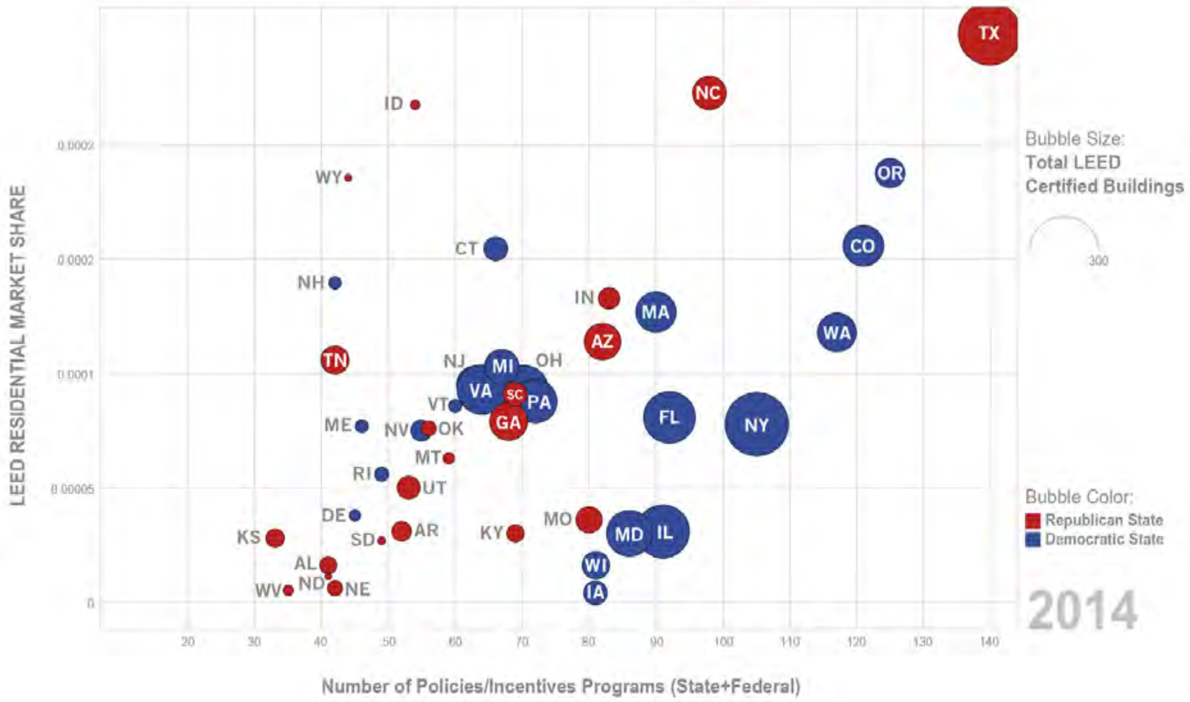

Figure 4. Policies/incentives and political map chart for LEED residential market share without outliers.

Table 1. Multiple regression analysis on policies/incentives and political mapping.

LEED Residential Market Share	Policies and Incentives Programs All States	Policies and Incentives Programs Without 8 Outliers	Political Orientation All States	Political Orientation Without 8 Outliers
□	-0.112	0.353	0.043	-0.076
p	0.074	0.000	0.014	0.022

Discussion – Potentials and Limitations

Third party certification for built environment praxis have the potential of being “carrots” in a world where policies and regulations may be perceived as “sticks” when reducing man-made environmental impacts. It is therefore necessary to understand relationships that aid communities in transitioning using such a positive reinforcement medium. LEED was developed in the United States and continues to grow in that market, and while it has been criticized for energy performance issues and certification level correlations with credits earned (Newsham et al, 2009), it is evident from this decade-worth of data analysis that the market continues to grow. We therefore discuss the potentials and limitations of such growth within the findings from a demographic and policy characteristics perspective.

Demographics

The results of this investigation indicate that median household income had a weaker influence on the adoption of LEED residential buildings in the United States over the past decade. However, level of education was a significant predictor of LEED residential market share, which suggests that number of LEED licenced residences in a community and level of education in that community are highly related. It is possible that lower educational attainment can imply lower income levels, but that is not necessarily a causal relationship (Blanden et al, 2004). Therefore, criticisms of LEED as “being only for the rich” (Cidel, 2009) are not necessarily valid in the case of examining a decade-worth of data. Nevertheless, other economic indicators could be further explored to confirm such inferences. For example, real GDP per Capita can be used as predictors for each state as an additional indicator of standard of living.

Policies and politics

Findings denote a moderately significant relationship between number of policies / incentives on both the federal and state levels with LEED residential market share. Such a directly proportional association suggests that the number of policies that administer green buildings aid transitioning LEED residential communities to proliferate and have their impacts supported through governance. Interestingly, research outcomes propose that being a republican or democratic presidential voting state has a much weaker influence on residential LEED market adoption. This suggests that previous research that specifies that "… political party has a significant effect on LEED concentration …" (Choi et al, 2011) may not be applicable in the case of LEED residential markets specifically. However, we used the presidential elections as the political mapping tool, and other political mapping approaches, such as political orientation of governors, may be used to confirm our findings.

Future research

The study suggests multiple directions for future research using the developed database, or through developing similar workflows. Further elaboration of demographic characteristics linked to LEED residential communities is needed, including multiple economic indicators. Policies investigated were at the federal and state level incentives, so future research can investigate enumerations of local policies as well, to study micro-level administration. Furthermore, special LEED practices that support transitioning communities, such as access to LEED Accredited Professionals (AP), should be incorporated and investigated as a potential defining characteristic of societies evolving towards low carbon practices, verified through third-party certification programs.

Conclusion

The comprehensive examination of LEED residential market adoption trends over time gives insight to the features of such communities in transit. We conclude in this paper that LEED residential market share growth has a stronger associative relationship with educational attainment over median household income, and with the number of federal and state policies over politics or the dominant political orientation of a state. The USGBC and similar third party certification entities which are interested in transitioning residential markets should be targeting states where number of policies supporting green building practices are growing, and where there is evidence of increasing educational attainment. Access to both these characteristics indicates inclination, not certainty, for transitioning through energy efficient and environmentally-aware practices based on historical data analysis. Future research should address limitations in the research method in terms of employing other robust data examination techniques such as clustering and computational complexity analysis, investigating other economic and policy indicators, as well as special features of such communities, such as the ratio of LEED AP per capita.

Acknowledgements

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Financial and Ecological Interest of Cohousing: Impacts of Autopromotion and Mutualization of Spaces and/or Systems

Dorothée Stiernon[1] and Catherine Massart[1]

[1] Architecture et Climat, LOCI, Université Catholique de Louvain, Louvain-la-Neuve, Belgium, dorothee.stiernon@uclouvain.be

Abstract: Rising prices in real estate and demographic evolution make access to the individual property an important issue for many families. This leads to a clear demand for low-cost constructions. In this perspective, the research Opticost - Technical-Economic Optimization of the Construction Costs - led by “Belgian Building Research Institute” aims to suggest alternative solutions. As project partners, “Architecture et Climat” worked on conceptual optimization in order to limit construction costs. This paper focuses on cohousing as an economical and sustainable alternative solution. Cohousing is commonly defined as "a place where several entities live and where self-managed privative and collective spaces are organized" (Definition from “habitat et participation”, a non-profit organization). Cohousing, this very complete model deals with the three pillars of the sustainable development. The research is based on interviews with architects, and an online survey sent to inhabitants of cohousing. Cohousing in general and four case studies in particular are detailed. Research is structured on the following key elements: a) Definitions of cohousing; b) Characteristics of cohousing: collective facilities and spaces; c) Objectives pursued in cohousing projects; d) Pros and Cons encountered in cohousing

Keywords: cohousing, construction costs, sustainable architecture, ecological solution, collective spaces

Introduction

Rising prices in real estate and demographic evolution (in particular: increasing number of family units) make access to the individual property an important issue for many families. This leads to a clear demand for low-cost constructions.

In this perspective, the research Opticost - Technical-Economic Optimization of the Construction Costs - led by “Belgian Building Research Institute” *(www.bbri.be)* aims to suggest alternative solutions according three different perspectives: technical, organizational and conceptual optimizations.

As project partners, “Architecture et Climat” worked on conceptual optimization in order to limit construction costs. We studied:

- Design of the whole project:
    - Multiple constructions: Economies of scale;
    - Contiguity: Economies on the number of facades;
    - Cohousing.
- Sustainable architectural design:
    - Bioclimatic: Compaction - Orientation – Glass surface;
    - Simplicity : Rationalization of the spaces - Similar and repetitive plans;
    - Size: Decrease of private surfaces thanks to the enjoyment of the common spaces.
- Temporal dimension:

- Energy savings;
- Adaptability and flexibility;
- Ease of maintenance.

Cohousing could be a strategy to reduce construction costs. This hypothesis has been the starting point of a research on cohousing.

Research is structured on the following key elements:

- Definitions of cohousing
- Characteristics of cohousing: collective facilities and spaces
- Objectives pursued in cohousing projects
- Pros and Cons encountered in cohousing

Methodology

To answer this issue, four Belgian cohousing projects were studied in detail:

- Biplan, in Brussels: 6 passive apartments
- Bois del Terre, in Ottignies: 6 energy-efficient houses and 1 shared home
- Brutopia, in Brussels: 27 passive apartments and 2 apartments very low energy
- Pic au Vent, in Tournai: 20 passive patio houses, 14 garden-houses with positive energy and 8 balcony-houses with positive energy

They were chosen according to:

- the availability of information: website, documentations, contact with architects
- their situation: 2 in a rural and 2 in an urban context;
- type of promotion: 2 projects in self-promotion with local input since the beginning; of the process and 2 projects where the architects are sponsors and look for buyers when the construction is ended.

Data have been collected from interviews with the architects of these projects, and from an online survey sent to the inhabitants of cohousing dating less than 10 years. The questionnaire of fifteen questions was realized via the site “SurveyMonkey”. Unfortunately, although the sending was relatively wide (public listing of cohousing, knowledge and addresses available on cohousing blogs), we only had only 18 answers.

After that these case studies are detailed in particular, an attempt is made to highlight possibilities and specificities related to cohousing.

Results

It is difficult to give a good definition of cohousing because its characteristics are multiple and often personal. Here are a few examples from interviews:

- “A life plan - A human adventure - A single place for several dreams - The support for an ecological and collective project;
- A tool to live better - The creation of a village in the city - A lifestyle together in the city, harmoniously and close to the other;
- A catalyst for a more intense and more just social life - A vector of self-fulfillment - A privileged place where the life of each is respected, maintaining a high degree of intimacy;
- A sharing of time, tasks, bad adventures and success - Meetings, intergenerational relations and common values;
- A laboratory, a compost of experiments - A beautiful experience of life where we learn every day - Another way to live - The future. "

Some people consider that inhabitants live real cohousing experience only if their commitment to the project takes place from the very beginning. However, from case studies analyzed in the research, even in case of project realized by architects or real estate developers, from the time occupants live in the building, they quickly feel like being part of a real cohousing project.

The most used definition of cohousing in Belgium is "a place where several entities live and where self-managed privative and collective spaces are organized" (Definition from “habitat et participation”, a non-profit organization - www.habitat-participation.be).
Indeed, many collective facilities and spaces might be integrated in a cohousing (Figure1).

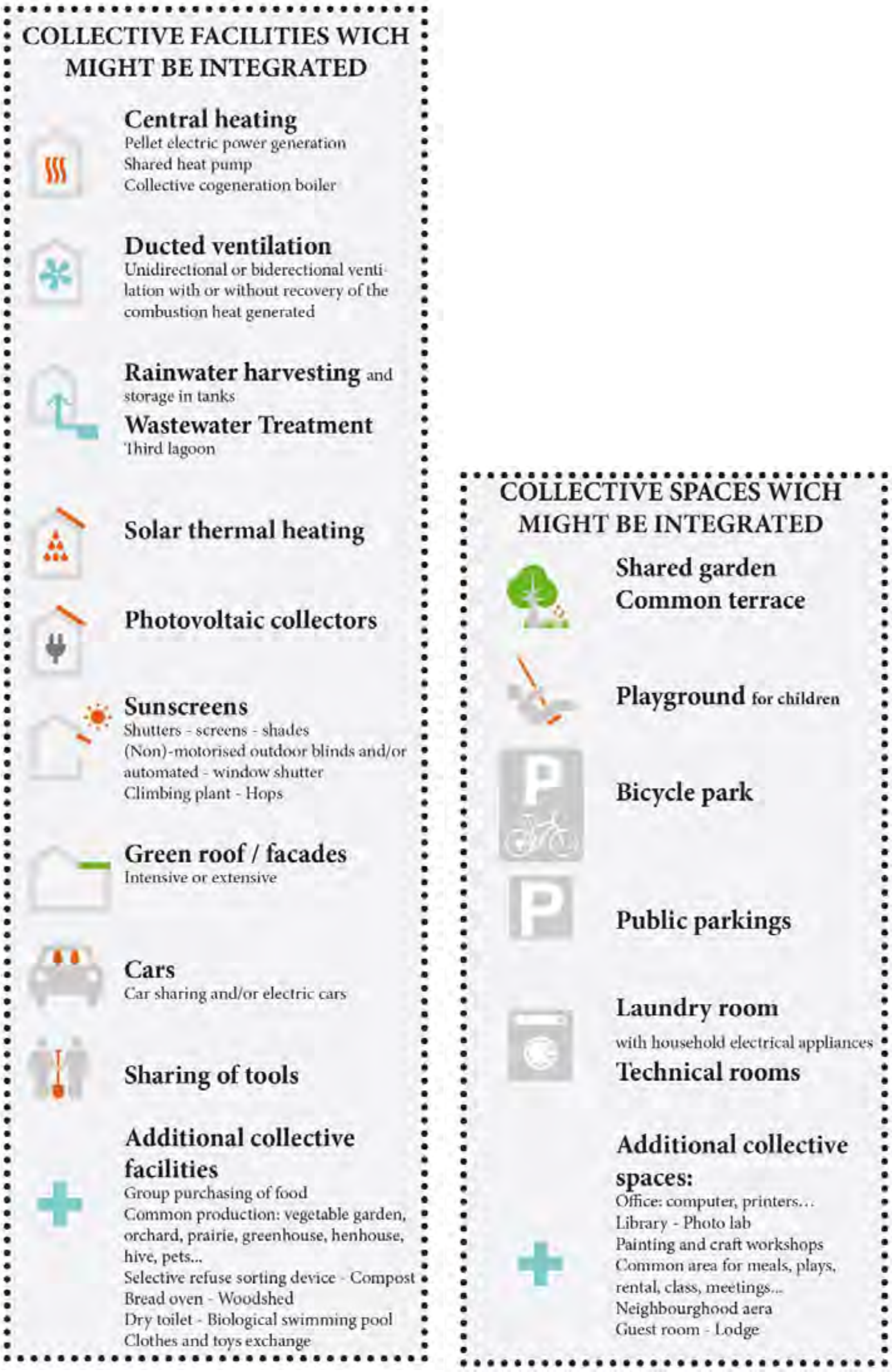

Figure 1. Examples of collective facilities and spaces, which might be integrated into a cohousing

Cohousing is more than a place to live. Cohousing is a way to develop a construction project but also a living mode. Analyze of case studies showed that many objectives were achieved, answering multiple challenges of sustainable development.

- Environmental objectives: reduction of environmental impacts of housing
    - Achieve high energy performance (reduce consumption and produce renewable energy);
    - Reduce greenhouse gas emissions;
    - Enhance biodiversity;
    - Reduce impacts on the water cycle.
- Social objectives
    - Create a community, sometimes to answer specific situation (support of single parents, intergenerational housing as a solution for old people…);
    - Collective commitment for a social or cultural project (support of precarious people, artistic project, religious community, vegetable gardening…).
- Economic objectives:
    - Answer to the housing crisis: way to reduce costs and access other categories of field / buildings to buy;
    - Cohousing ease action to fight against individualism and short term profit dictatorship.

According to case studies, interviews, definitions and context, cohousing cannot be considered only for its economical features. Those very complete models deal with the three pillars of the sustainable development: environmental, social and economic.

The following tables (Figures 3-5-7-9) show Pros and Cons encountered in cohousing for economic, social, architectural and environmental aspects. Extracts from interviews and literature have been added to illustrate the topics with numbers or facts from the field.

Pros - Economic	**Cons - Economic**
Organization and management: - Participation in a common project; - Self-promotion	Organization and management: - Time and energy consuming project for the inhabitants.
« Generally, you can save 20% on overall costs with self-promotion. » (DELLESKE A., architect, Freiburg - Germany, 2011)	
Design of the whole project: - A single team of architects and/or only one planning permission for the whole housing project; - Multiple constructions - Contiguity	Setting a longer timescale: - Slowness on administrative processes; - Very long set up the process. Problem for new constructions: - Important common investment before each entity has its own part.
Sustainable architectural design: - Bioclimatic - Simplicity - Size	Sustainable architecture: - Costs of the construction higher than for a traditional project.
« Apartments can be smaller thanks to the common spaces and to a rationalization of	*« (…) The diversity of housing pulls a largest number of architectural specificities (…). The*

<table>
<tr><td>the plans, for an economy from 10 to 20 %, according to the experience feedback. » (PARASOTE, 2011)</td><td>additional costs for this freedom of design can be estimated at 5 % of the total cost. » (PARASOTE, 2011)</td></tr>
<tr><td colspan="2">« A factor of economy is in the rationalization of space by an intelligent spatial design to limit corridors and by limitation of private space by mutualizing the common spaces. For example, a washing machine occupies approximately 0,80 m² on the ground, that is (for an average price of EUR 2.000 including taxes) EUR 1.400 including taxes of construction costs! The mutualization in a laundry allows to save space and money. It is the same for the guest room (…). We consider approximately 10% space savings. » (PARASOTE, 2011)</td></tr>
<tr><td>Renewable energy: Investment divided among the inhabitants – Power saving.</td><td rowspan="3">
Figure 2. Terrace of cohousing « Brutopia »
Stekke + Fraas Office</td></tr>
<tr><td>«A house has a dry toilet which offers 35 % water savings and composting."» (COUPEZ J., architect, about cohousing “Bois del Terre”, 2016)</td></tr>
<tr><td>Construction :
- Only one contractor for the whole project;
- Possibility for self-construction;
- Multiple constructions: Economy of scale;
- Same and local materials: Savings due to bulk and local purchase;
Fixed costs shared between all inhabitants in proportion to surfaces.</td></tr>
<tr><td rowspan="2">Collective facilities and spaces:
- Improving homeownership affordability;
- Bigger surface area in collective buying than in private;
- 100% enjoyment of facilities and additional surfaces but only a part of the costs;
- Decrease of the private surfaces, the main characteristic of cohousing.
Fixed costs shared between all inhabitants in proportion to surfaces.</td><td>Collective facilities and spaces:
- Initial investment not to be neglected.</td></tr>
<tr><td>« Common spaces have a price which you should not neglect, but in my case I pay only 50 thousandth and I benefit from 1000 thousandth of use. » (A resident of cohousing “L’Echappée”, 2016)</td></tr>
<tr><td>Exchange of services:
- Daily group purchases;
- Common Production: kitchen gardens - Orchards – Henhouses;</td><td></td></tr>
</table>

- Household chores and works; Children’s care - Assistance to older people.	

Figure 3. Economic Pros and Cons

Pros - Social	**Cons - Social**
Sharing: - Participation to the common project - Investment according to our interests and skills; - Mixing of rooms and buildings functions; - Collective facilities and spaces which are places of meetings and intergenerational exchanges; - Household chores and works; - Children’s care - Assistance to older people.	Organization and management: - Time and energy consuming project for the inhabitants: too long process for some families who have to give up the project for financial or organizational reasons - Loss of energy and enthusiasm for some inhabitants because of the slowness of the steps; - Difficulty in making discover this concept to professionals: Entrepreneurs - Solicitors - Bankers; - Big management of information, meetings and decision-making; - Definition of the Internal Rules to make it easier to live together, to protect the intimacy and to organize the use and the maintenance of collective facilities and spaces.

Figure 4. Guest rooms of cohousing “Pic au Vent” 36°8 Office

Relationship: - Social mix and age diversity - Meetings - Extension of the social networks; - Human and intergenerational relationship - Participation of all the generations in the process -	Relationship: - Social mix limited by a relatively homogeneous level of income bound to the intrinsic cost of the project;

Decrease of the individualism and the solitude; - Equality - Solidarity - Consensus - Feeling of membership; - Confidence - Collective dynamics - Effect of mass.	- Difficulty of integration and living together while protecting its values and his personal projects; - Required to accept the differences and the complementarities; - Difficulty to find consensus, to satisfy everybody and to adapt itself to the evolution of needs and objectives of everyone.

Figure 5. Social Pros and Cons

Pros - Architectural	**Cons - Architectural**
Individual, collective and transition spaces: - Collective spaces which allow to enjoy additional surfaces; - Joints of private and common spaces to favor the meetings and to protect the intimacy; - Evolutionary and flexible private spaces to everyone can appropriate the personal space and to adapt it to the evolution of the family unit.	Architectural options: - Non-priority aesthetic; - Need of soundproofing between housing.  Figure 6. Square of cohousing « Bois del Terre » Coupez Office
Conceptual optimizations: Cohousing offers an ideal context for the conceptual optimizations (multiple constructions; common ownership; bioclimatic architecture; simplicity of volumes; adjusted surfaces).	

Figure 7. Architectural Pros and Cons

Pros - Environmental	
Cohousing are often a perfect opportunity to build more durably : - Sustainable energies (reduction of the energy impact; decrease of CO_2 emissions) - Local materials.	
Optimization of the housing stock: - Reduction of grey energy thanks to the density of built;	

- Collective facilities and spaces - Pressure strategies to improve public transport of the sector: bike paths - shared bikes - shared cars.	 Figure 8. Orangery of cohousing « Biplan » BxlECO Office

Figure 9. Environmental Pros and Cons

Conclusions

Economical approach was the starting point of the research project. Cohousing case studies quickly appeared to be difficult to compare with individual housing from many aspects linked to the process and related life mode.

Anyway, it seems also clear that none of the case studies analyzed could strictly be considered as a low cost solution. Costs are not low but there are lower than costs of a traditional individual housing with similar performance, equipment and available space.

Cohousing characteristics always depend on choices of developers and occupants and reducing the costs is only one of many objectives pursued in the projects that have been studied.

As a conclusion, cohousing can be considered as a way of developing housing projects and living mode that permits to achieve a high quality of life and to answer challenges of sustainable development with relatively low extra-costs.

Many cohousing projects are currently being developed in Belgium and work could be done to ease the process and give support to developers to encourage this type of housing solution for its social economic and environmental advantages.

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Transport

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Factors motivating bicycling in Sydney: Analysing crowd-sourced data

Parisa Izadpanahi[1], Simone Z. Leao[2], Scott N. Lieske[3] and Chris J. Pettit[2]

[1] Department of Architecture & Interior Architecture, School of Built Environment, Curtin University, Perth, Australia, parisa.izadpanahi@curtin.edu.au;
[2] City Futures Research Centre, University of New South Wales, Sydney, Australia;
[3] School of Earth and Environmental Sciences, The University of Queensland, Brisbane, Australia

Abstract: Devising smarter strategic plans for more efficient modes of transport is fast becoming a priority for city planners and transport agencies. Having Sydney, Australia as case study, we analysed 6,932 GPS tracked cycling routes acquired from the RiderLog smart phone application to better understand interactions between bicyclists and the urban environment that encourage bicycling behaviour. Our approach used regression methods to identify a set of variables that can best predict the distance that cyclists ride. Gender, distance of the cycling track along parks and coastal areas, distance of the cycling track along commercial areas, percentage of the slope of the cycling track, and percentage of the type of cycling infrastructure (separate, shared, mixed, and no cycling lane) were considered as the potential predictor variables. Results indicate that although most of these variables could significantly predict the distance that cyclists ride, the distance of the cycling paths along parks and coastal areas and along commercial areas had the greatest contribution to the total R square. The findings of this paper provide important metrics which can inform city planners on how to improve attributes of the urban environment associated with bicycle tracks to motivate cyclists to ride longer distances.

Keywords: Bicycling behaviour, environmental attributes, crowd-sourced data, infrastructure, and facilities

Introduction & Background

There is a developing consensus around the effectiveness of bicycling to address the ills of the early twenty-first century cities. Public health crises, such as chronic disease associated with physical inactivity) (Pratt et al. 2014), environmental concerns (transition to less carbon intensive cities) (Haines and Wilkinson 2014) and costly infrastructure expansion are leading to a global shift toward more sustainable transportation, including bicycling (Bertolini et al., 2008, Hood et al., 2011).

Bicycling offers both personal health benefits as well as broader environmental benefits. Benefits to health result from decreased air pollution and increased physical activity. Research has shown the built environment can be significantly correlated with the physical activity behaviours of city residents (Saelens et al., 2003, Giles-Corti et al., 2011). Environmental benefits results from mitigation of the negative externalities of traditional fossil fuel heavy transportation systems including decreases in air pollution, greenhouse gas emissions as well as reductions in traffic accidents, congestion and noise (Bertolini et al., 2008, Sener et al., 2009, de Hartog et al., 2010).

At the same time as this developing interest in bicycle transportation, there is an increasing interest from city planners and policy makers in evidenced based research in active transportation (Pettit et al., 2016). Understanding the flows of people moving through the built environment is a vital source of information for the planners and policy makers who shape our cities (Pettit et al., 2016). However, information about bicyclist preferences, infrastructure and policies that may encourage bicycling and the effectiveness of bicycling infrastructure investment are limited (Pucher et al., 2010, Hood et al., 2011, Broach et al. 2012). Agencies seeking to improve bicycling infrastructure, safety, and mode share may be done through collection of data on bicycling routes, route attributes, and rider demographic information (Hudson et al., 2012).

There is an emerging body of literature presenting the results of investigations of bicycling infrastructure on bicycling levels and cyclist route choice. Dill et al. (2009) observe that bicyclists are "probably" (p. S104) going out of their way to take advantage of bicycling infrastructure. Hood et al. (2011) found preferences for bike lanes, especially for inexperienced riders. Broach et al. (2012) found cyclists value off-street paths and side streets with traffic calming but bike commuters are more sensitive to distance and less sensitive to infrastructure. Similarly, Aultman-Hall (1997) found high quality off road paths are used infrequently by bike commuters. However, Krenn et al. (2014) found cyclists prefer bicycle lanes and bike paths over the shortest possible routes. They also found bicyclists select routes with green infrastructure (including sporting fields) as well as water and aquatic areas. Wendel-Vos et al. (2004). also reported that the time spent on bicycling was associated with green and recreational space such as sport grounds and arks Sener et al. (2009) found traffic signals, stop signs, street crossings, speed limits, on street parking and continuity of bicycle lanes to be important in route choice.

The literature puts forward a number of a factors beyond bicycling infrastructure that influence bicycling activity. Bicyclists seek to minimize route distance (Dill 2009, Hood et al., 2011) Broach et al. 2012). Dill et al. (2009) found cyclists avoid high traffic streets. Krenn et al. (2014) found residential density and commercial areas to be higher along the shortest possible cycling routes suggesting bicyclists are avoiding these areas on longer rides. In contrast, Winters et al. (2010) report a positive correlation between the presence of more commercial land use and increased bicycling behaviour. Proximity to commercial areas may indicate the desirability of passing through such areas, potential positive or negative impacts of vehicular parking on bicycling in these areas (for example, hazards associated with bicycling past parallel parked vehicle) and/ or the influence of the often-reduced speed limits in these areas.

Sener et al. (2009) found travel time (for bicycle commuters) and motorized traffic volume are the most important elements of route choice. However, Hood et al. (2011) found traffic (both volume and speed) not to impact bicyclist preferences. Bicyclists are consistently found to avoid steep slopes (Aultman-Hall et al., 1997, Sener et al., 2009, Menghini et al., 2010, Krenn et al., 2014) Broach et al. 2012, , especially female cyclists and for commuting (Hood et al., 2011). Specific to Sydney, Ellison and Greaves (2011) note the relevance of slope including the possibility that the hilly terrain of Sydney may contribute to the low cycling mode share. As reported in Krenn et al. (2014), Titze et al. (2010) found high quality neighbourhoods with numerous trees positively influence cycling.

Sener et al. (2009) and Broach et al. (2012) highlight the potential importance of individual characteristics on route choice and infrastructure preferences. Sener et al. (2009) include age, gender, employment, cycling experience, and reason for trip in their analysis.

Broach et al. (2012) found studies indicating experienced cyclists prefer lanes to separate paths or simply hold no preference for bike lanes. They also found evidence women and less-experience cyclists prefer separate infrastructure, less traffic and lower speeds.

Dill (2009) and Pucher et al. (2010) specify data and methods limitations in cycling research that may impact our understanding of links between cycling levels and infrastructure. These include the inherent limitations of stated preference studies, small sample sizes in revealed preference studies, as well as lack of route and infrastructure information in large sample studies. Taking advantage of new technology to confront these methodological issues, there is an emerging bodies of studies noting the opportunities provided by smartphones for the collection of bicycling travel data (Hood et al., 2011, Hudson et al., 2012). When combined in a crowd scale, mobile phone data may have the capacity to reveal macro behavioural patterns (Pettit et al., 2016) including infrastructure preferences. Some mobile phone applications currently available for bicycling include BikeNet, Biketastic, SocialCycle, MapMyRide, iBike, Cycle Meter, Strava, and RiderLog.

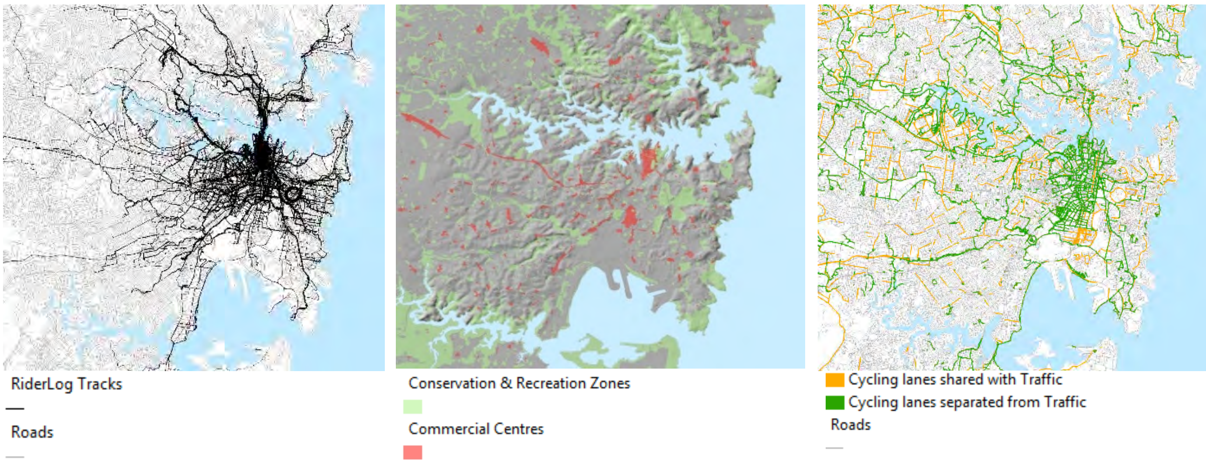
Methodology

This study investigates contextual factors that contribute to cycling by encouraging people to ride longer distances, considering that longer cycling journeys promote physical activity to an intensity that according to the World Health Organisation lead to significant health improvement (WHO 2002). This understanding can be used to plan and implement healthier urban design solutions. RiderLog provides information on the cyclists and their journeys, but not about the context or environment where these journeys occur. Therefore, we integrate contextual information including: (i) slope, (ii) cycling infrastructure, (iii) proximity to parks and coast and (iv) proximity of commercial centres to the cycling routes. When integrated into a matrix, this information can be analysed through statistical methods to investigate their interdependencies.

Study Area Description

This section provides visualisations and brief descriptions of the characteristics of the study area in relation to the input data. Figure 1a shows the itineraries performed by voluntary bicyclists and recorded by the RiderLog mobile app from 2010 to 2014. It indicates a wide geographic distribution with a concentration of trips in the central area of Sydney. A dynamic visualisation of the cycling movement in a typical day in Greater Sydney based on RiderLog data used in this study can be found at https://cityfutures.be.unsw.edu.au/cityviz/cycling-sydney/. The overall distribution has an average of 9Km/journey, with 1/3 of the journeys between 7 to 9 km, and 2/3 of the journeys below or above that mark, roughly equally divided. This wide distribution provides a good case study to examine differences affecting cycling trips with varied distances. Figures 1b and 1c present the spatial distribution of urban characteristics analysed in this study as contextual factors affecting bicycling. It is hypothesised that these factors have an influence on how people cycle across the city in terms of their route selection and overall riding distance.

Figure 1b shows parks and commercial centres overlaid to the topography. Sydney has a varied topography and the high slope in some areas may affect cycling. In general, slopes up to 2% are considered the best for cyclists of any age or fitness level; slopes between 2-5% are still considered appropriate; slopes between 5 to 10% may not be appropriate for children, elderly, or people with limited fitness; slopes above 10% should be avoided, but they can be cycled for very short distances. Overall, the RiderLog routes are performed in areas with gentle slopes appropriate for cycling (63% are below or equal to 5%); however, the topography of the city seem to impose some proportion of cycling at higher slopes. Sydney also has a good distribution of parks. 32% of the distances ridden in all journeys were along parks; indeed only 1% of the journeys did not crossed any park, and 92% of the journeys had at least 10% of the ridden distance along a park. An analogous situation was found for commercial areas; 22% of the distances ridden in all journeys were along commercial centres; only 3% of the journeys did not crossed any commercial area, and 77% of the journeys had at least 10% of the ridden distance along a commercial area. Figure 1c shows cycling infrastructure overlaid on the road network. It is possible to see the concentration of infrastructure in the central area of Sydney and along few major roads, and also some lack of connectivity in the existing infrastructure. A visual comparison between Figure 1a and 1c seems to indicate that cyclists prefer routes with cycling infrastructure. Indeed, the proportional share of the distance of all RiderLog routes indicate that 64% of the distance ridden is along some sort of separated or shared lanes; and 36% mixed with traffic.



a. GPS tracked cycling routes map b. Slope, parks and commercial centres c.Cycling infrastructure

Figure 1. Cycling and contextual factors data in Greater Sydney from 2010 to 2014

Data Integration

A series of spatial analyses in ArcGIS were performed to integrate cycling patterns and geographic characteristics into a database suitable for statistical investigations of influence and interdependencies. Table 1 describes the spatial analyses derived from related data inputs.

The result of the spatial analysis applied to the geographic input layers is a large table integrating all the required data for statistical analysis. Each row of the table describes one cycling route (route id), while each column qualifies the route in terms of varied characteristics of the cyclists (rider id, gender, age), of the cycling journey (distance, and duration), and of the context/environment (slope, proximity to parks, proximity to commercial centres, cycling infrastructure).

Table 1. Spatial analysis for data integration

Goal	Spatial analysis	Output (New Table Fields)
Slope on cycling routes	Production of a slope map in % based on contours (raster, 50m); Classification of slope into 4 classes related to difficulty to cycle: 0-2%, 2-5%, 5-10%, >10%; Convert slope class raster map into vector; Intersect cycling routes to vector slope class map; Calculate distance and % of the route into 4 slope classes.	Route distance 0-2%; Route distance 2-5%; Route distance 5-10%; Route distance >10%; % route 0-2%; % route 2-5%; % route 5-10%; % route >10%
Proximity to parks on cycling routes*	Create a buffer of 10 meters around parks; Intersect cycling routes to park buffer map; Calculate distance and % of the route along parks.	Route distance close to parks; % route close to parks
Proximity to commercial centres on cycling routes*	Create a buffer of 10 meters around commercial centres; Intersect cycling routes to commercial centres buffer map; Calculate distance and % of the route along commercial centres.	Route distance close to commercial centres; % route close to commercial centres
Type of cycling infrastructure on cycling routes*	Classify cycling infrastructure into 4 classes according to safety for cycling: 1; Create a buffer of 25 meters around cycling infrastructure; Intersect cycling routes to cycling infrastructure buffer map; Calculate distance and % of the route along cycling infrastructures.	Route distance Infra 1; Route distance Infra 2; Route distance Infra 3; Route distance Infra 4; % route Infra 1; % route Infra 2; % route Infra 3; % route Infra 4

**RiderLog is subject to GPS imprecision, such as less or lost signal in urban canyons or GPS drift when rider is stationary. These imprecisions cause cycling routes to be 'around' roads, instead of perfectly aligned with them. Therefore, buffers around target areas (commercial centres and parks), were used in order to capture the majority or all the cycling routes in close proximity. For the same reason, topography was characterised as an average % slope within a cell with 50 metres spatial resolution.*

Regression Analysis

Multiple regression analysis was conducted using the SPSS Statistical; software package to identify a set of variables that can predict the distance cyclists ride. This analysis also indicated the relative contribution of each identified variable in predicting the total distance ridden. Multiple regression indicated how much of the variance in distance ridden is explained by gender, the distance in meters of the track along parks and coastal areas, the distance in meters of the track along commercial areas, percentage of the slope of the cycling track, and percentage of the type of cycling lane (separate, shared, mixed, and no lane).

Identifying outliers:

The initial attempt at assessing the normality of the distribution of data for both independent and dependent variables showed the data were not normally distributed. Therefore, outliers were identified through calculating z-scores (standardised residual) for all the variables. Through this process, 259 samples were deleted, because they had z-scores above the cut-off value of 3.29. The outliers were scrutinised for better understanding of the attributes they carry. It was identified that a large part of the outliers were related to highly-fit cyclists performing very long distance rides. Although they represent a genuine part of the data, they are a minority that skew the distribution. It was a decision of the authors to delete these records from the overall data of analysis. This decision was justified on two grounds: first, the study will at this stage focus on the majority of ordinary cyclists; and second, by turning the distribution into normal, more robust statistical analysis is possible. After this deletion, a histogram of the data was checked and the outcome corroborated that the distribution became normal.

Multiple regression was run to predict the total distance of the track ridden by the cyclists as recorded by RiderLog (Route_Distance). Gender and some environmental attributes such as the distance of the track along parks and coastal areas (DistParks), distance of the track along commercial areas (DistComm), percentage of the slope of the track (slope <=2%, slope >2 and <= 5%, and slope > 10%), and percentage of the type of cycling lane were considered as the potential predictors of the distance ridden. Preliminary analysis were conducted to ensure no violation of the assumptions of normality, linearity, multicollinearity, and homoscedasticity.

Results indicated that 69% of the variance in Route_Distance is explained by the model, F (9, 6663) = 1657.697, p<.0005, adj. R2=.69. All the variables except percentage of the overall track with shared cycling lane added statistically significantly to the prediction, p < .05. Regression coefficients and standard errors can be found in Table 2. DistParks made the strongest unique contribution when the variance explained by all other variables in the model was controlled for (β =.525). The second strongest independent variable in terms of the power of prediction was DistComm (β = .343), the third was percentage of the overall track with slope > 10% (β =.076), and the forth was percentage of the overall track with mixed traffic lanes (β =.227). The rest of the predictors, although significant, had a minor power in predicting the distance ridden.

Semi-partial correlation coefficients (Part-correlation) indicated that DistParks, DistComm, percentage of the overall track with slope > 10%, and percentage of the overall track with mixed traffic lanes respectively contributed 22%, 10%, 4.7% and 2.8% to the total R2. Regression coefficients and standard errors can be found in the following table.

Table 2. Summary of multiple regression analysis – Dependent variable: Route_Distance

Predictor Variable	**B**	**SE_B**	β	**Part-Correlation**
Intercept	245.896	243.338		
Gender	298.284	74.855	.028	.027
Distance to commercial areas (DistComm)	1.040	.022	.343	.318
Distance to Parks and coastal areas (DistParks)	1.253	.018	.525	.470
% of the overall track with slope <= 2%	3551.991	200.030	.150	.121
% of the overall track with slope >2 and <= 5%	-669.270	333.528	-.021	-.014
% of the overall track with slope > 10%	12469.117	504.025	.258	.219
% of the overall track with mixed traffic lanes	5822.758	180.877	.227	.168
% of the overall track with no cycling infrastructure	-1129.253	225.874	-.035	-.034

*Note: * p < .05; B= unstandardized regression coefficient; SE_B= standard error of the coefficient; β =standardized coefficient*

Discussion and Conclusion

This research considers several features as part of the built environment. Results suggest that to encourage cyclists to ride longer distances, some strategies work better than others. The findings of this paper suggest that proximity of cycling tracks to parks and coastal areas, and proximity of cycling tracks to commercial areas are the two most powerful predictors of the distance bicyclists ride based on the contextual factors examined. This finding is also supported by many studies conducted in different geographical contexts. In one such study conducted in Odense, Denmark, a positive correlation between the presence of cycling routs, and bike racks in urban green spaces and the increased level of physical activities was found (Schipperijn et al., 2012). This outcome is particularly important in planning of the new cycling tracks in cities, such as Sydney that has considerable area of coastal lands and parks.

Distance of the track along the commercial areas was the second most powerful variable in predicting the distances that bicyclists ride. Rider preference for commercial areas may be due to favourable infrastructure (e.g. dedicated cycle infrastructure), lower driving speeds in commercial areas as well as the desirability of commercial areas as destinations or stops along bicycling journeys. Moreover, safety of the cycle tracks is one of the determinants of bicycling behaviour which is strengthened where the tracks are along commercial areas, shops, retails, and small businesses.

Slope, or what has been reported as hilliness, has been shown as one of the determinants in cycling behaviour in literature (Parkin et al., 2008). Since Sydney has a hilly terrain, slope has been considered as one of the potential predictors of the distance ridden. This study result indicated that slope of the track can significantly predict the distance that bicyclists ride. Percentage of the tracks with more than 10% slope were the most powerful determinants and the tracks with less slope had considerably less predictive power, although statistically significant. As such, this study suggests that to encourage people to cycle longer distances, it is important to design cycling tracks with less than 10% slope.

The presence of bicycle paths and lanes is frequently associated with increased bicycle commuting (Reynolds et al., 2009). As such, the type of cycling lane was also taken into consideration in this study. Three variables of Percentage of the Overall Track with Shared Cycling Lane, Percentage of the Overall Track with Mixed Traffic Lane, and Percentage of the Overall Track with No Cycling Infrastructure were entered into the multiple regression model to evaluate their predictive power. The result of the analysis suggested that all types of lanes except the Shared Cycling Lane could significantly predict the length of the ride. According to this outcome, as long as cyclists have a path, whether it is designed only for bicycles or it is a shared path (Shared with pedestrians), the type of the path does not have a significant power in predicting the length of their ride. However, having a track with no cycling infrastructure, or with mixed traffic lane (mixed with cars) will significantly and negatively correlate with the length of the ride. Higher percentages of the track with mixed or no traffic lanes will discourage people for riding longer distances.

The analysis presented here suggests there is substantial evidence that environmental variables are consistently associated with bicycling behaviour. The authors would also like to highlight opportunities for further investigation and methodological improvements. This study has combined GIS recorded data with the Riderlog recorded data. Therefore, some of the trips could be slightly different from the ones that actually took place. Acknowledging this limitation and other limitations mentioned earlier in the paper, it is worth to mention that the simulated bicycle routes in this study are the most possible accurate representation of the journeys taken place, and is much more fine grained than traditional methods which rely on set point traffic counts or participant surveys. Further research needs to be conducted to confirm the cross-contextual validity and reliability of the result. Furthermore, there are several nuanced measures, such as weather condition which has not been included in this study and needs to be addressed in future. Despite certain limitations, this research has implications for city planning to facilitate a more active life style for citizens, and identifies promising directions for future studies.

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Ethane—a green(er), clean(er) transportation fuel opportunity

Kimberly King[1], Lindsay Leveen[2] and Mark Johnson[3]

[1] Out Think The Box, Baltimore, Maryland, USA kimgerly@outthinkthe box.net
[2] GoEthane!, Sausalito, California, USA, lleveen@gmail.com
[3] Mark Johnson, Mark V Systems, LLC, Houston, Texas, USA, markvsystems@gmail.com

Abstract: Given their reliance on emissions-heavy air transport and shipping transport, package delivery companies are challenged to reduce their carbon footprints. UPS-type hydraulic hybrid ground fleets can be greener by optimizing energy use in these low-emission vehicles, since stopping, and starting is key to saving fuel in these types of vehicles. With a residence time of only 78 days in the troposphere after combustion, more economical ethane (C_2H_6) can be a greener bridge in the transportation sector. Ethane can act as an alternative fuel stock to expand this vehicle truck option, provide an oil saving solution, and reduce global warming emissions without drivers changing their driving habits. This is the best use of ethane adding the highest value using the simplest technology. In 2015, an ethane bi-fuel field trial was conducted in Jewett, Texas, USA using a modified fuel injection system in a Ford F150 4.6L Triton pickup truck. Emissions results returned 2 ppm particulate matter, 0.00% Carbon Monoxide (CO), 0.01% Carbon Dioxide (CO_2), and 20.79% Oxygen. Performance results returned torque slightly better than gasoline, and fuel injection time slightly slower than gasoline, providing better combustion. A higher, 9% increase in miles/GGE (gasoline gallon equivalent) efficiency versus gasoline was produced, resulting in 30% less CO_2/mile on the same vehicle compared to gasoline. We are proposing a follow-up test. This test will show the ethane truck functions well in colder conditions, heavy traffic, that it meets or exceeds California's air pollution laws, and that the test is repeatable. This paper will provide some background on ethane production and usage, and assert that it constitutes a better fuel system for the entire United States.

Keywords: ethane, transportation, alternative, fuel, low-emission

Introduction

Municipalities around the world are working collaboratively to be the cleanest, most environmentally sustainable cities on the planet. Clearly there are issues from the latent CO_2 produced from fossil fuels, but also Liquified Petroleum Gas (LPG). These municipalities' ultimate and cumulative end goal is to reduce worldwide carbon emissions utilizing cleaner burning fuels for their vehicles. This is a noble effort. However, there are other ways to reduce carbon emissions that can achieve the same carbon reduction objective by utilizing readily available, alternative fuel stocks such as ethane. Use of ethane can result in significant decreases in energy costs, yielding positive results in these municipalities. Ethane as a green(er) clean(er) transportation fuel can be a significant opportunity for the urban and rural environment as it decomposes much faster than LPG and fossil fuels.

Given their reliance on emissions-heavy air transport, package delivery companies, and mass transit fleets are challenged to reduce their carbon footprints. A way to green their ground fleets is to optimize energy use in low-emission vehicles. Hydraulic hybrid propulsion systems deployed in the newer UPS-type delivery trucks use energy efficiently, producing less pollution than conventional delivery trucks. (USEPA 2007) UPS-type trucks are rarely used on the highway; stopping and starting is key to saving fuel with a hydraulic hybrid. Bus fleets are using Liquified Natural Gas (LNG) to lower their carbon footprint, but LNG is not an optimal fuel source. Ethane is a scalable solution down to a mid-size car, so taxis could be a part of the solution.

Ethane use can expand these vehicle options, providing an oil savings solution by reducing global warming emissions without drivers changing their driving habits. This is the best use of ethane adding the highest value using the simplest technology. There are two main areas of focus in current market trends for messenger and delivery companies with urban located large truck fleets:

- 'burn less' using hybrid vehicles; aero dynamic optimized vehicles, maximum speed reduction, or electronic modified engine control.
- 'burn clean(er)' by electric vehicles deployment and use of alternative fuels.

United Parcel Service (UPS) operates about 7,200 low-emission vehicles running on alternative fuels and technologies. (editors 2014) FedEx has one of the largest, in-service worldwide hybrid-electric fleets in the industry; almost 2,000 alternative energy vehicles. Deutsche Post DHL has 3000+ vehicles. (Connor 2013), (drrnm5 2011), (Simanaitis 2007)

If a more economical fuel source providing better carbon emissions, and is scalable down to automobiles is required, then ethane should be considered.

Project Scope

Back in 2014, UPS started using propane (C_3H_8) fuel in a test. (Lopez 2014) Ethane (C_2H_6) is far less expensive than C_3H_8, yet has similar range and is less carbon intensive. The market is for this fuel can be utilized throughout the United States, as can be used in existing gasoline engines and access existing fuel stations. The performance compared to the standard gasoline engine or LNG vehicle is improved—same driving range, less cost, less carbon emissions. Comparatively, Compressed Natural Gas (CNG) has range limitations; compressed ethane does not. Ethane has more hydrogen content per BTU than gasoline $(CH_2)_n$, hence less CO_2/mile. (Leveen 2014) This favorable result was proved in a field trial in the spring of 2015 with a dual-fuel (gasoline-ethane) Ford F-150 Triton Pickup Truck; Nucor Steel Corporation in Jewett, TX, USA sponsored this field trial. There is a real savings, financially and environmentally, by choosing ethane as a transportation fuel.

Aims of the Project

Our aim is to recover ethane in the oil refinery process or natural gas capturing process. Instead of using ethane as fuel input to boilers at refineries, or in the manufacture of plastics, we propose it be re-purposed as a transportation fuel for the use in railroad locomotives, package delivery trucks, or for similar delivery applications in other, appropriate industries. This proposition uses ethane as a transportation fuel by optimizing the storage pressure rating for the ethane on the vehicle in the onboard storage tank and via existing fuel control systems for gasoline engines. As long as the ethane is compressed to its critical pressure, and is below its critical temperature, it will be a liquid in the gas cylinder/tank. (Leveen 2014)

The forecast is that there is a glut of ethane way into the future. Hence, the arbitrage continues unless added uses, like the one we propose, will make this fuel useable throughout the USA. Industry partners like Nucor Steel Corporation have expressed interest in this opportunity. Many are looking to convert ethane to ethylene and petrochemicals, or to ship it to Europe for conversion to petrochemicals. However, the largest value add with the least capital intensity is to simply compress ethane and have a fuel that is more than twice the energy capacity as CNG, and almost as energy dense as gasoline.

Background

What is ethane?

Ethane (C_2H_6) is a liquid petroleum gas (LPG). Liquified natural gas (LNG) is primarily, 98+ % methane (CH_4), which is cooled to cryogenic temperatures to maintain a liquid state. Methane will always be a gas unless cooled below -82.6 °C (-116.68 °F). Unlike methane, due to it's very low critical temperature, ethane liquefies under compression, and does not require cooling or cryogenics.

Table 1. Critical Temperatures of Hydrocarbon Fuels

Hydrocarbon Molecule	Chemical Formula	Critical Temperature (°C)
Methane	CH_4	-82.3
Ethane	C_2H_6	+32.2
Propane	C_3H_8	+96.0
Butane	C_4H_{10}	+152.0

Source: The Engineering Toolbox (Editors 2015)

In a cylinder, if the temperature of ethane exceeds +32.17 °C, then it will become a gas. This is why the cylinder is only filled to 35% of its water volume with the liquid ethane when filled at a temperature below 32.17 °C. Cylinders holding ethane are designed for 1800 psi (pounds per square inch) or greater, yet ethane will only have a working pressure of about 600 psi.

This the most important point about ethane—its half-life in the troposphere is exponentially less than any other hydrocarbon fuels without sacrificing BTU's. (Hewitt 2003)

An expert reference point: Lindsay Leveen

Mr. Lindsay Leveen, a thermodynamics expert, chemical engineer, and award-winning journalist. He was awarded the Professional Development Award for his lifetime of achievement in chemical engineering by the American Institute of Chemical Engineering (AIChe). Mr. Leveen has consulted to major corporations in areas of energy deregulation, fuel cells, telecommunication, alternate fuels, thin film deposition, power generation, transmission and distribution, as well as a variety of other process-based technologies. At one time, he worked at L'Air Liquide where he was responsible for developing large onsite supply systems for industrial gas plants.

Mr. Leveen has visceral knowledge and a concrete understanding of ethane, and ethane's merits for application in the transportation sector. He recommends keeping ethane in the USA instead of offshoring it for use as the precursor feedstock in the manufacturing of plastics.

In late 2013, Mr. Leveen asserted compressing ethane and using it as a transportation fuel, hypothesizing compressing ethane would be more valuable than cracking it to make ethylene, the precursor feedstock for manufacturing plastics.

In 2015, Mr. Leveen predicted there would be a glut of ethane due to all the hydraulic fracturing activity in the Marcellus Shale Formation and Bakken Shale Formation. (See

Figure 1) In the fall of 2015, Mr. Leveen revealed in a report to the California Air Resources Board (CARB) there would be a glut past the year 2020.

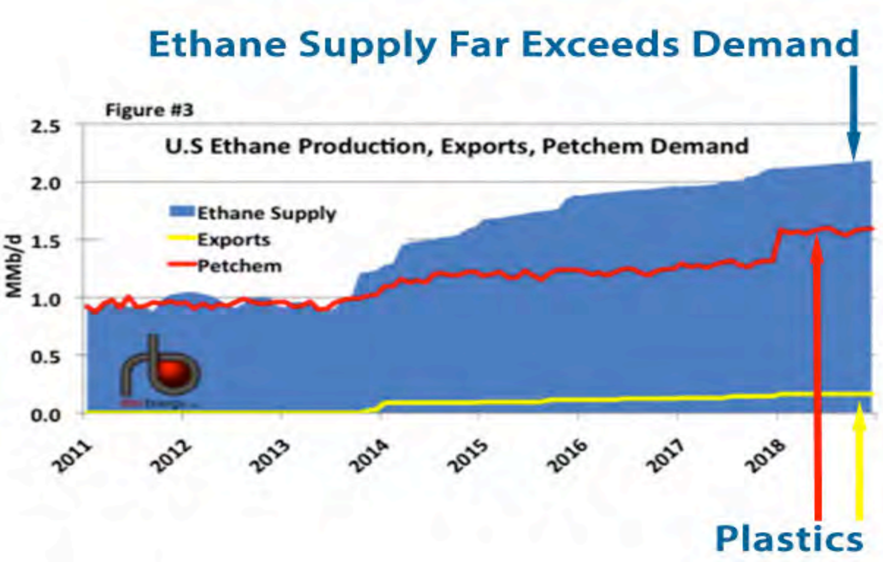

Figure 1. USA Production Exports Petrochemical Demand [Annotated] (Brazeil 2013)

In February 2017, business and financial services company, Moody's Corporation issued an affirming report on the strong LNG demand from Asia, "…will not be enough to absorb the fresh supply capacity coming online…the market will not rebalance until the early years of the next decade when global demand and LNG import infrastructure catches up with supply." (OGJ 2017)

Financial benefits

Compared to an ethane cracker, which takes upwards of four years to bring online, an ethane compression station requires two months to commence operations. (Leveen 2014)

A guesti-mate of the available feedstock of surplus ethane is about 200,000 barrels/day from the USA refining process alone. (Brazeil 2013) If one considers the shale gas in Pennsylvania and Colorado, without including Texas, there are probably about 400,000 barrels/day in surplus.

Figure 2-A shows ethane prices versus other liquid fuels in $/MMBtu. Ethane is 29 cents/gallon. A gallon of ethane has 66,000 BTU LHV (lower heating value), hence it is about half a gallon equivalent of diesel, and 0.6 gallon equivalent of gasoline. This means ethane can be bought from the LPG (Liquified Petroleum Gas) fractionator at about 50 cents/gallon on a gasoline equivalent. The NYMEX price of gasoline is over $3/gallon. And so, the big arbitrage is to place the bulk ethane in tube trailers and then smaller amounts into welding tanks aboard vehicles.

The forecast is that there is a glut of ethane way into the future. Hence, the arbitrage continues unless added uses, like the one we propose, which will be used in vehicles in the USA. As an example, industry partners like Nucor Steel Corporation have expressed interest in this opportunity, because they were investigating using ethane as a fuel for their service vehicles fleet from their natural gas wells.

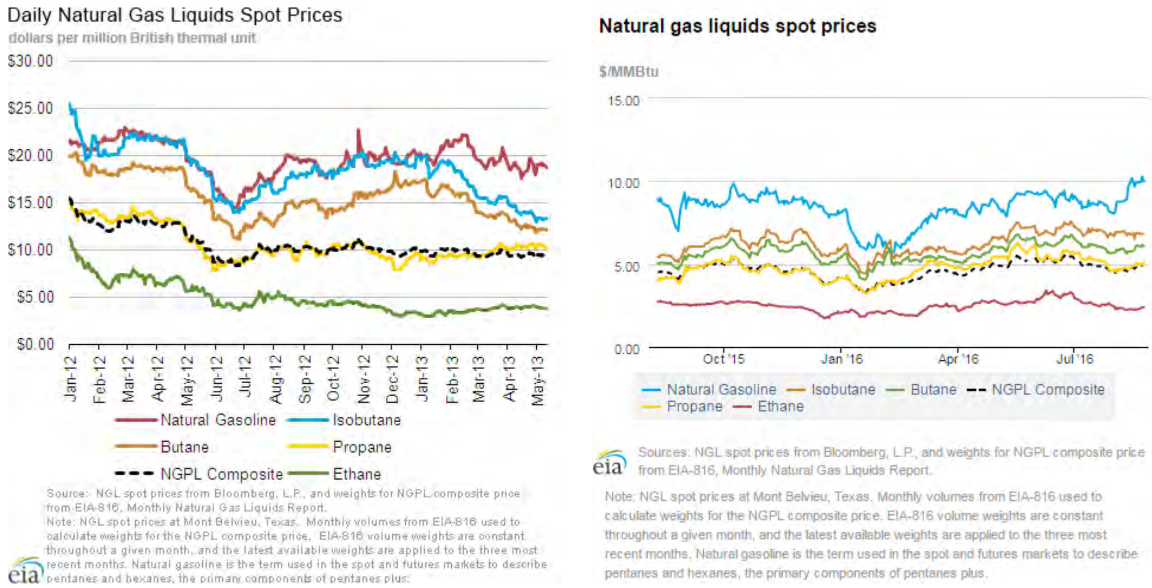

Figure 2-A&B. Natural gas liquid spot prices [January 2012 - May 2013 & October 2015 – July 2016] (USEIA, Natural gas liquids prices trend down since the start of 2012 2013), (USEIA 2016)

Environmental benefits

Compared to methane (CH_4) with a residence time in the troposphere (the lowest region of the atmosphere) of about 10 years, and carbon dioxide (CO_2) with a residence time of about 100 years, ethane's residence time is only 78 days in the troposphere. (Hewitt 2003)

The 100-year indirect global warming potential (GWP) is 5.5 for ethane, much lower than the 25 GWP of methane. (Yang 2015) This is due the highly reactive, short-lived, ubiquitous hydroxyl radical [OH], which oxidizes/destroys ethane as part of the photochemical process. (Hewitt 2003) By comparison, the rate of methane (CH_4) oxidation by OH is very slow, between 100 times and 1000 times slower than other organic compounds. (Crutzen 2006)

Sources of ethane come from oceans, vegetation, fossil fuel (conventional natural gas, shale gas, coal), modern microbial (wetlands, rice paddies, ruminants, termites, and landfills/waste) and biomass burning sources. (Sherwood 2017)

The Ethane Truck

For the first time in the world, a Ford F 150 4.6 Triton committed by Nucor Steel USA was converted to successfully use ethane fuel in a bi-fuel (gasoline or ethane) injection system. (See Figures 3-10) A prototype system was installed on the base of the IMEGA GAME LPG/CNG System, and re-designed with a 3-stage regulator. (See Figure 6) New ethane-dedicated software to optimize the system and record emissions was deployed. Compressed ethane fuel was transferred from a welding tank to the onboard fuel tank strapped into the truck bed. (See Figures 5)

The field trial was conducted in the town of Jewett located two hours travel by automobile northwest of Houston, Texas, USA. Field trial dates occurred on 10 August 2015 through 9 September 2015. Temperatures ranged from 71° F to 106° F at the start of each drive, and weather varied between sunny, overcast, and clear.

Figure 3. Ford F150 Triton Ethane Truck

Figure 4. Imega Cockpit Switch and LED Gage

Figure 5. Ethane Modified CNG Tank w/solenoid valve

Figure 6. Reformer & 3-Stage Regulator

Figure 7. Ethane Fuel Injector Rail

Figure 8. Pressure Electronic Control Unit

Figure 9. NIMITZ Electronic Control Unit

Figure 10. Infrared 5 Gas Analyzer

To view, go to *IMEGA USA Ethane Bi-Fuel NUCOR's Ford F150 4.6 Triton* YouTube VIDEO

Ethane emissions testing results

- Low NOx, low HCs (hydrocarbons)
- Zero Carbon Monoxide (CO) emissions
- 30% lower than gasoline in CO_2/mile
- Complete combustion of HCs—No methane slip like CNG or LNG
- 86 mg/mile of non-methane HC (hydrocarbon) plus NOx
- Ethane and other HCs react out in the catalytic converter
- Lowest emissions of all transportation fuels
    - Exception: Hydrogen made from PV energy or wind energy

This Ford F150 Pickup Truck model was featured in a recent policy brief produced by The Baker Institute for Public Policy. This brief revealed "thirstier vehicles offer the highest return on fuel efficiency investment." (Collins 2017)

Conclusions

Ethane when compressed and cooled with cooling tower water is a liquid under pressure; it is non-cryogenic. Companies like L'Air LIquide sell ethane in welding cylinders that are almost full of liquid ethane. An L'Air Liquide 44 litre cylinder (also known by some companies as an 1A cylinder size) with ethane has 32 pounds of ethane. This has a lower heating value of about 650,000 BTU or about 5.7 gals of gasoline. (Leveen 2014) The same cylinder if filled with methane, compressed natural gas (CNG), would hold about 290 scf (standard cubic foot) of methane at 2,400 psi (pounds per square inch), and only have 267,000 BTU. (Leveen 2014) Ethane has about 2.5 times as much energy for the same volume and mass of storage. Vehicle range depends on the BTUs stored—hence rather than CNG, compressed, liquid ethane for vehicles is proposed. This schema should be workable for a(n) (extremely) large truck fleet operator in collaboration with a company like L'Air Liquide to perform the compression and logistics.

Compressed ethane will be as good as Liquified Natural Gas (LNG), and sans the additional energy input to cool to super low temperatures. Ethane will not require additional expense for cryogenic vessels/tanks required in the cryogenic process. Compressed Natural Gas (CNG) has a limited driving range and is challenging to store. Whereas, the process proposed in this paper will yield a lower carbon fuel for a lower price than diesel or gasoline, and driving range will not be sacrificed much.

Our group seeks funding to execute a field trial in the State of California to prove the viability of the ethane vehicle requirements. Funding would also include infrastructure needs to fuel vehicles. The final report will not only show that ethane meets and exceeds the California air pollution requirements, but also reveal the costs required to convert fuel stations and vehicles to ethane usage. We believe we can also produce data to prove this fuel could be used throughout the USA as a game changer in atmospheric pollution and green gas emissions.

Many are looking to convert ethane to ethylene and petrochemicals, or to ship it to Europe for conversion to petrochemicals. **However, the largest value add with the least capital intensity is to simply compress ethane and have a fuel that is more than twice as effective as CNG, and almost as energy dense as gasoline.**

Industrial carbon producers in the steel and iron, petroleum refining, manufacturing and transportation sectors realize they must take measures to further limit climate change. These sectors must act, especially since government policy is increasing the issuance of climate instability (change) measures requiring them to pay more damages—which in turn, could affect their profits. Looking at relative responsibility based on relative profits in the supply chain activities on carbon emissions and the climate, ethane should be a worthwhile investigation.

Acknowledgements

The authors gratefully acknowledge the help of those who provided extensive feedback and resources to conduct a pilot, proof-of-concept field trial in the spring of 2015 in Jewett, TX, USA—demonstrating ethane can be a cleaner, greener transportation fuel.

Notably, Brad True at Nucor Steel Corporation provided unwavering support for this endeavour, by offering frank feedback, scintillating suggestions, and constructive critiques, but by generously providing funding and resources to conduct the field trial project. The Jewett, TX staff, Bryan Linton and Matt Way, also deserve recognition for their contributions, support, and knowledge-base transfer.

The remarkable vanguard Danilo Gardi at Imega International USA Alternative Fuel Systems was instrumental and critical at steering the injection system design and direction of this pilot project proof-of-concept research—ultimately proving ethane can be game changer as a future transportation fuel stock.

Joe Marcenillo at Imega International USA Alternative Fuel Systems who constantly girded us on with his unwavering and unconditional support.

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A Design Framework for Sustainable Mobility Hub Networks in Mid-sized Cities

Christian Martinez and Tarek Rakha

School of Architecture, Syracuse University, Syracuse NY, USA

Abstract: Contemporary society is dependent on mobility and transportation in urban and regional settings for work, services and leisure activities. Recent changes of perception have shifted the outlook of car-centric plans toward more sustainable and shared modes which are regarded as more efficient for air quality, health, and other environmental factors. When considering mid-sized cities we see that their performance issues may be partly due to population density declination, climate, available infrastructure, etc. This paper develops a framework for the design of a mobility hub network in mid-sized cities that challenges the established method of infrastructure planning. Through the analysis of three urban conditions (urban sprawl, downtown core, and institution node) this paper presents a method for an integrated urban architectural system that fosters sustainable urban mobility. These include design guidelines for mobility hubs, development of scenarios for arranging integration of programming and infrastructure, and strategies for mobility network optimization. The research method combined qualitative analysis for existing conditions, categorization of infrastructure and services available and finally mapping and projections for future scenario development of sustainable urban transportation. The investigation is concluded with a representation of design strategies for a site in Syracuse, NY USA as a test bed for the study.

Keywords: Mobility hub, Network, Mid-sized City, Sustainability, Transportation

Introduction

The dependence on single-occupancy vehicles in cities for mobility is the lead contributor to the 26-39 percent in transportation energy consumption nationwide (NY Power Authority, 2015). In recent years, American cities have been working toward reducing transportation energy consumption through planning efforts that emphasize human-powered mobility and public transportation modes (Litman, 2015). The consideration and development of mobility hubs in these efforts have been underlined as a key component to transportation planning and as positive contributors to the successful management of movement in a city using multiple-modes of travel (Metrolinx, 2008).

The Mid-sized City

In the context of this study, we characterize the mid-sized city as one with a city population under 500,000.

A mobility hub network for a mid-sized city under these assumptions will be understood to be different from that of a larger city. Mobility hub operations in larger cities tend to focus on the opportunities for overlap of various robust transit modes and networks as well as the use and activities set within the hub itself. This is possible because of opportunities derived from conditions of congestion, which mid-sized cities lack as a resource (Chakrabarti, 2013). The developed framework in this paper differs in application due to conditions of smaller density, available infrastructure and distances between destinations. The analysis aims to expose a phenomenon of activity hubs and opportune moments of transit mode transfers. The mobility hub for a mid-sized city is thus a destination-based model that capitalizes on an available infrastructure with much reliance on the private sector and community based efforts to generate links to zone of high activity.

Framework

This paper presents a framework to generate a mobility hub network in mid-sized cities. The method is developed for urban and architectural design, where the outputs are guidelines for the design of a mobility hub and design of its urban network. The paper includes: a methodology that details analysis procedures for precedents and city characteristics, followed by the results of research focused on implementation at three urban conditions that differ in scale (urban sprawl, downtown core, and institution node), and concludes by presenting a framework that suggests future implementation in other mid-sized cities. The city of Syracuse, NY USA was analysed and tested through the presented framework for a mobility hub network, focused on sustainable transportation.

Methods

Figure 1 demonstrates the developed framework. A targeted collection of information pertaining to characteristics of the city specific to urban mobility and destination institutions and activities is analysed to determine travel behaviour and patterns in the city, key areas to capitalize on existing infrastructure and what types of mobility hubs could be implemented. A set of mobility hub design guidelines is also generated for application at the hub locations.

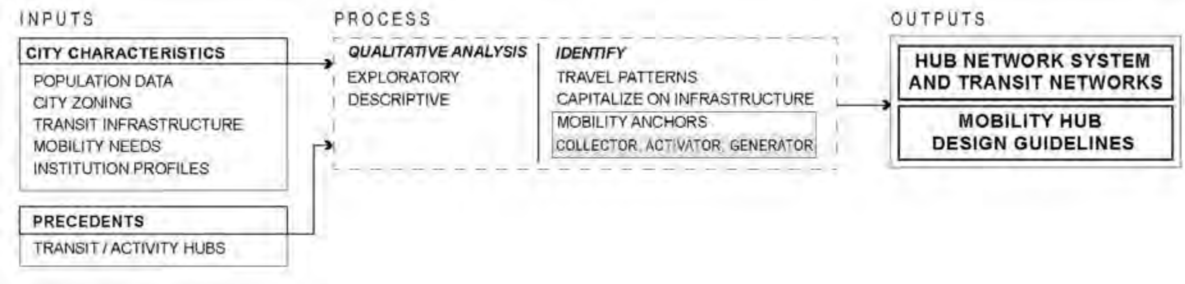

Figure 1. Presented framework.

Inputs

Information about the mid-sized city that detail demographics, current physical conditions and infrastructure, available transit services, mobility needs and major institutions is collected for analysis. This information aids in assessing transit modes for consideration, population and demographic travel information to accommodate and address any proposed programmatic needs for additional transit modes.

City Characteristics

Characteristics information relevant to mobility consists of a compilation of census travel data and local/municipal travel studies. Information on new mobility options and needs as determined by the city through travel action plans is to be collected to anticipate the accommodation of future infrastructure and services, especially those that influence sustainable modes of travel.

City characteristics should also include information related to major institutions and destinations/activities. This should focus on setting up profiles for institutions and areas that are accessed and support mobility patterns in the city. Based on areas and zones with significant travel and density, these profiles can be analysed for consideration as a mobility anchor point.

Precedents
Precedent survey includes a collection of information on projects that focus on the relationship between the overlap of transit infrastructure and opportunities for support programs. These precedents provide examples of mobility hubs to catalogue design strategies for the possible configurations of transit and destination junctures (Figure 2). Precedent search is not limited to scale, as a qualitative analysis is conducted to determine application at an appropriate urban condition of the same scale.

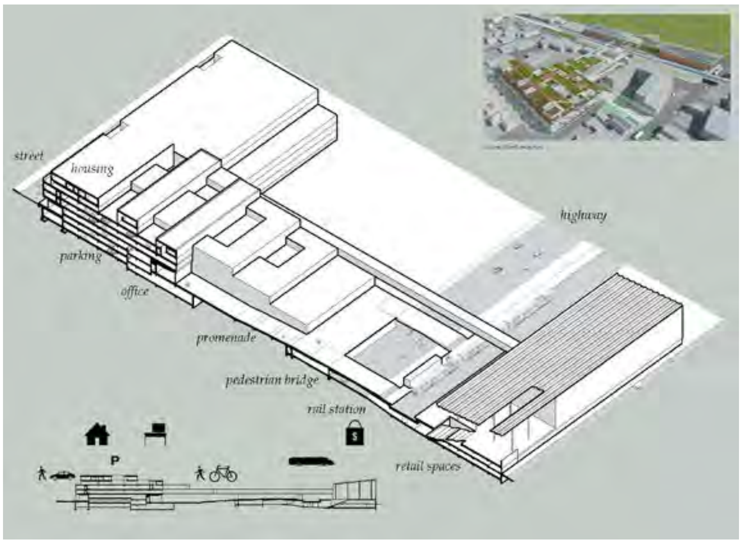

Figure 2. Parking Plus precedent by LTL Architects. Image produced by authors.

Process

Existing Conditions Opportunities
A qualitative analysis approach is used to understand travel patterns of the city from the characteristic inputs. From these patterns we can generate information that locates major travel corridors, available infrastructure, mobility services and frequented key institutions. In addition to capitalizing on overlapping infrastructures an emphasis on areas or pockets of density is a factor in determining hub locations. Infrastructure that fosters human-powered mobility (walking and biking) and public transit are primary considerations in this process. Links to car infrastructure are considered for partial trip use with a hub or nearby location offering the opportunity to drop-off or dock a vehicle and complete the trip by an alternative mode.

Anchoring programmatic needs to the existing networks and infrastructure is also considered to implement the success of new mobility modes. The proposed mobility modes will include new systems of infrastructure for additional mobility support and integration with the existing conditions. Additional travel modes create a range of travel opportunities and a flexible comprehensive network.

With the key institutions identified there are opportunities for inclusion of supplementary activity programs to further increase activity levels. These could include housing, office, grocery, retail, recreation, day-care, etc. if not already available. Supporting programs should be identified to balance the travel schedule to the area allocating more programs that offset that of the key institution. For example, in the study, the downtown urban district and core has a business district with many of the city’s major employers. This area primarily operates during weekday business hours. Additional programming may be added for activities past work hours or on weekends to generate constant flow.

Mobility Hub Anchors

Identifying mobility hub locations in the mid-sized city relies on the ability of an area to perform as an anchor point to sustain activity. All mobility hubs in the network of a mid-sized city are mapped with the intent of them operating as a city wide system. Some criteria to consider are maintaining a quarter-mile radius of activity zone or destination area from each mobility hub and also keeping a two mile distance between hubs. This would accommodate pedestrian trips from the hub location to the destination and bike or public transit trips between hubs. Each hub location would differ in operation, size and type (Engel-Yan and Leonard, 2012). Figure 3 represents hub location types that are categorized based on existing conditions and prospects to link with destination activities. Collector hubs are larger hubs that are located in proximity to active areas with good supporting infrastructure and would be primary hubs in the network, meanwhile activator hubs make an effort either to introduce new activities or new modes of transit. Generator hubs attempt to service areas that lack infrastructure or activities for any sustainable mobility.

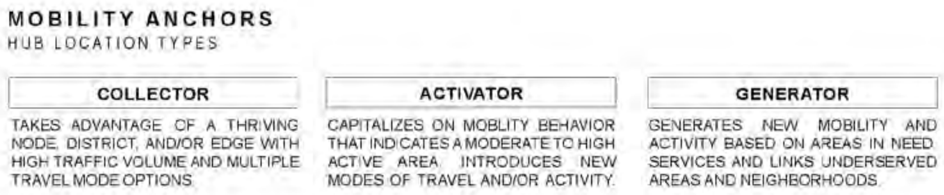

Figure 3. Mobility hub types based on activity and infrastructure parameters.

Output – Network and Hub Design Guidelines

Two outputs are determined from processes outlined above. A scheme for a network of mobility hubs is derived with mobility hub locations and impact areas. The second output is a set of guidelines for mobility hub design.

Results

The method was applied to Syracuse, NY as a test-bed for a mid-sized city. The mobility hub network for Syracuse operates as a destination-based hub system. Each mobility hub weighs equally in the system to each other despite different characteristics and locations. Programs vary based on the available infrastructure and characteristics of density and scale. From the three urban conditions derived from the analysis of Syracuse, (urban sprawl, downtown core, and institution node) each are ascribed a hub as a link in the system.

Syracuse Profile Inputs

The survey conducted on city characteristics of Syracuse resulted in finding population demographics and major transit infrastructures. Areas with higher rates of access, the major corridors and thoroughfares that connect them and the institutions at play were found for analysis (Figure 4).

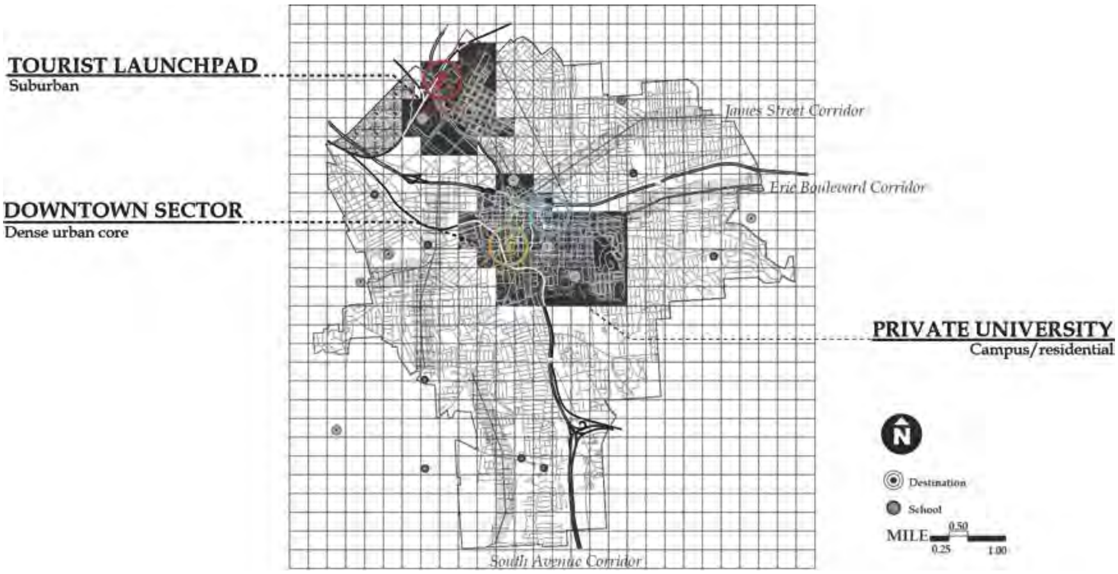

Figure 4. Syracuse general profile. Major thoroughfares and institution locations. Image produced by authors.

Exploratory Analysis

Qualitative analysis of the city characteristics was done to identify opportunities for hub locations. Three key areas were identified as potential collector hubs because of the infrastructure resources and institution profiles.

Sprawl-City Edge

As noted earlier, Syracuse has been experiencing a consistent decrease in the residential population of the city while the residential population in the neighbouring suburban towns has increased and continues to grow. With consideration of a large population of travellers to the city coming from outside the city limits by car the scope of the mobility hub is altered to address users from greater distances. The focus here is on utilizing the strong network of car infrastructure and regional transit to draw in commuters within a 10 – 20 minute commute area of the regional zone at the edge city. At the site of the Destiny Mall in Syracuse and Regional Transit Centre we find these two systems converge (Figure 5).

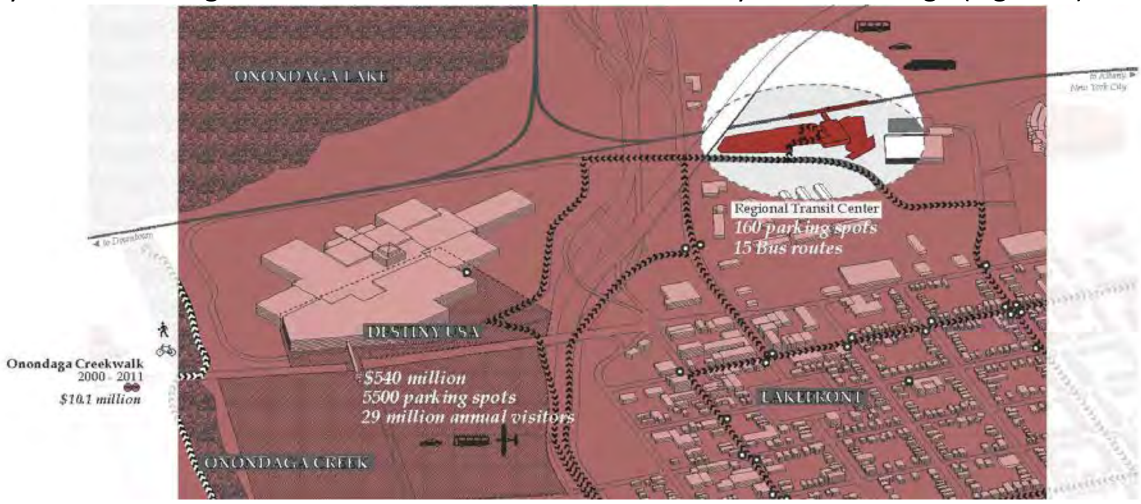

Figure 5. City Edge. Sprawl characteristics and transit catalysts. Image produced by authors.

Downtown-Urban Core

The downtown zone consists of an array of destinations and an urban density and size that can capitalize on walking and biking, the mobility hub for this location is focused on linking the current mobility systems to seamlessly integrate all modes of transportation. A priority here is to manage parking for the business and convention districts from travellers of the region at a particular location and convert the rest of the trip to the downtown destination via human powered mobility or public transportation. One of the main issues to overcome is the convenience of the use of the automobile to and within this district.

Institution Node

From the survey we find there are two major institutions located within the same neighbourhood. These are Upstate Medical University and Syracuse University. These universities have the highest numbers of employees in the region among two institutions. In addition to the large numbers of trips made to these locations for work they offer additional destinations for education, recreation and entertainment. The existing transit infrastructure relies mostly on driving and parking. The trip is then completed by either walking or shuttle network provided by the institution. These institutions have established themselves as walkable communities within the primary zone of activities from the campus setup that promotes walking.

Syracuse Mobility Hub Network

The mobility hub network for Syracuse in the context of this study would be comprised of thirteen hubs. Each would operate across three scales based on level of activity, density and available and future infrastructure. The two-mile distances between hubs are intended to provide adequate coverage and accessibility for travel by public transit or service a fifteen minute bicycle ride (Figure 6).

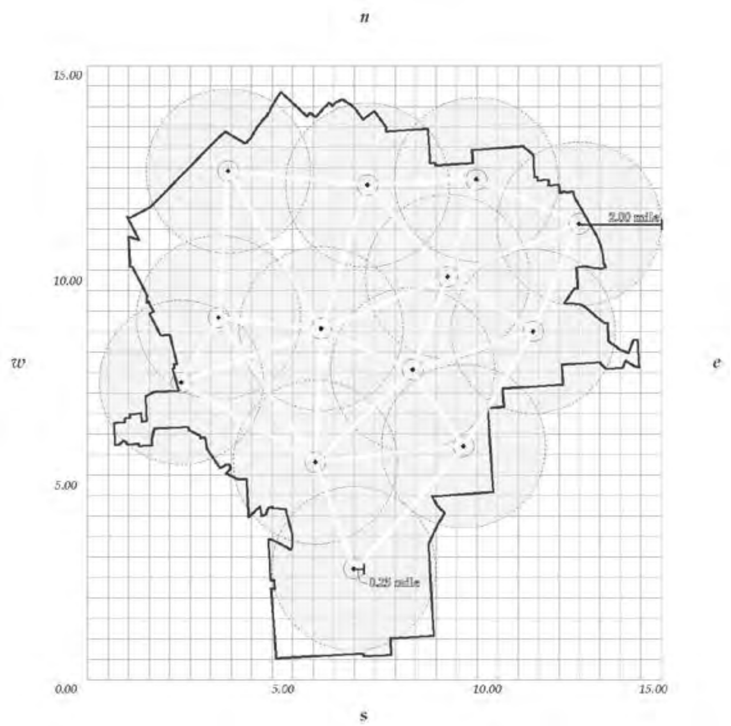

Figure 6. Syracuse mobility hub network. Image produced by authors.

Mobility Hub Design Guidelines

In addition to the hub design considerations stated in the methods, the guidelines for the design of hubs in Syracuse include some of the following strategies:

Site specific locations – Locations for infill to be considered at an opportunity where two transit mode infrastructures overlap. Placement at the edge or centre within proximity of destination is decided based on anticipated impacts.

Convergence of infrastructure – All accommodating infrastructures are to be housed within the hub. The moments of convergence can be stacked, flanked side by side, staggered or overlapped.

Integration of mixed use programming – Activity drivers to stimulate economy and attraction to the site as well as mobility services should be configured in the hub in collaboration with the design of the convergence of transit infrastructures.

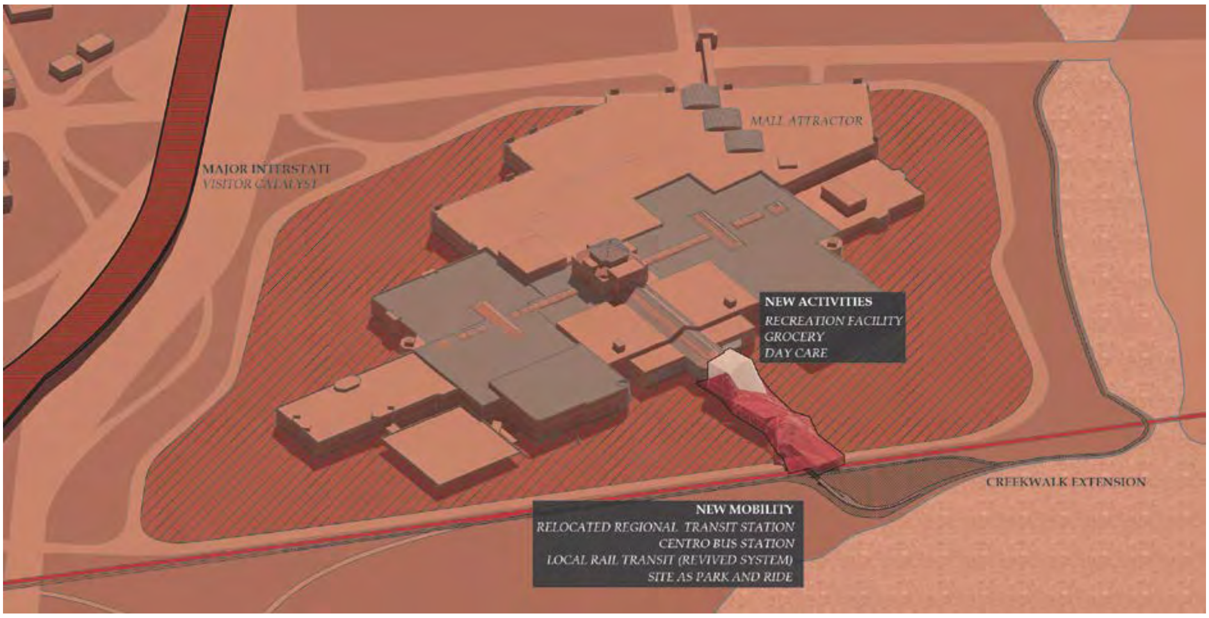

Figure 7. Sprawl-city edge transit hub. Image produced by authors.

Discussion

It is worth noting that the solution of a mobility hub network is not a one size fits all. This framework is intended for a working method in creating a network and guidelines for the design of a mobility hub. When applied to future case studies it is inevitable that design of the network and mobility hubs will be different despite following similar principles of accessibility, activity and sustainable mobility.

Supporting Institutions

In the case of mid-sized cities, a destination based model would rely on significant support from the private sector. The role that the destination plays in this model anticipates generous provisions from the affiliation with key institutions. Therefore, the institutions of a city are crucial resources for the feasibility of a hub network.

System Phasing and Prioritization

Recent literature suggests that in developing the network there is prioritization in the phasing of mobility hubs (Engel-Yan and Leonard, 2012). Planning for improving transit infrastructure is a major priority to perform as a catalyst for successful mobility and accessibility between hub destinations. Once an adequate transportation system is in place, collector hubs would be first in priority while other hubs would be phased shortly after their completion. The goal would be to make sure that there are initial drivers for established the network followed by activator and generator hubs that increase accessibility to and from areas that require more support.

Conclusion

The proposed scheme for a mobility hub network in Syracuse focuses on and anticipates new mobility for the city that is driven by travel to key destinations and sustainable travel mode choices. Based on the mobility hub design guidelines, a design approach can be followed for implementation at other suggested locations across the city. Although not a conventional element of urban design or urban planning, mobility hubs can play a vital role in motivating human-powered mobility, sharing economies and public transit in other mid-sized cities and because of the convenience of car use in these cities a network approach of mobility hubs as presented through this framework could provide an alternative. Further investigations into this matter should outline quantitative assessment and feedback mechanisms that can predict potential outcomes of the results.

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PLEA 2017 EDINBURGH
Design to Thrive

Human-powered Mobility Programming Needs in Mid-sized US Cities: the Case of Syracuse NY

Tarek Rakha and Christian Martinez

School of Architecture, Syracuse University, Syracuse NY, USA

Abstract: Metropolitan regions in Upstate New York evolved over the past 50 years following a pattern of sprawl without growth in population, similar to many other post-industrial regions across the United States. This phenomenon increased the number of trips via Single Occupancy Vehicles (SOVs). This paper assesses the feasibility of developing and promoting human-powered mobility systems in mid-sized US cities in order to counter reliance on SOVs. The study focuses on Syracuse, NY, as a case study of a downtown core with a sprawling suburban growth, and examines complementary efforts in four other NY state cities as well as twelve motivated cities across the US that joined the National Association of City Transportation Officials (NACTO). Through the quantitative and qualitative examination of infrastructure projects and their effect on mode-share in the 17 examined cities, this paper presents comprehensive sustainable mobility programming needs for Syracuse, NY, as well as other mid-sized US cities. The investigation is concluded by presenting eight action categories in walkability/bikeability enhancement for sustainable mobility scenarios.

Keywords: Mobility, Walkability, Bikeability, Infrastructure, Syracuse

Introduction

The past century has seen a steady decline in human-powered transportation in urban areas. Throughout history, towns and cities were planned around accessibility to resources such as water and market places. Urban form followed the transportation technology available, and where a horse or donkey could take you was the limit for growth (Muller, 2004). However, each step forward in the field of transport technology development negatively affected the pedestrian environment. The degradation of the walkability and bikeability of cities was strongly related to the loss of intimate scales in streets as it became a separator between person and automobile. With the awareness of such auto-dependency, researchers, governmental agencies, and activists have begun to address these issues simultaneously. The concept of “walkable cities” as the foundation for a sustainable development was reborn. As populations switch to alternative modes of transportation (namely walking, biking and public transit), the benefits are demonstrated in different aspects and scales. Examples of these are reduction in congestion, lower carbon footprint, energy efficiency and lower noise and air pollution (Forsyth et al, 2008). Comprehensive sustainable transportation research has investigated issues such as automobile access (Nordfjærn et al, 2016), automobile dependence (Buehler et al, 2016) and the effect on sustainable mobility adoption as well as infrastructure investments and its effect on behaviour change (Ogilvie et al, 2004). Nonetheless, research investigating multiple cities to inform human-powered mobility planning is limited.

Similar to many other post-industrial cities, the Syracuse, NY, metropolitan area has evolved over the last 50 years following a pattern of sprawl without growth. Employment opportunities are concentrated within the city, and the majority of employees live in suburban and exurban communities. Mobility between home and work, and within the city during work hours, is highly dependent on personal automobiles. In 2010, vehicles travelled approximately 893.6 million miles in Syracuse, and the resulting GHG emissions totalled 551,850 metric tons. The city's recent Energy Master Plan envisions a 31% reduction in average municipal vehicle fuel consumption achieved via fuel efficiency measures; however, increased adoption of sustainable transportation alternatives—such as walking, biking and public transit will be necessary to achieve substantial citywide reduction in GHG emissions (NYPA, 2015).

This paper assesses the feasibility of developing and promoting human-power mobility systems in Syracuse, NY, as a case study of a downtown core with a sprawling suburban growth. The study contextualizes Syracuse through descriptive research and mapping analysis followed by examining 16 other complementary mid-sized US cities. This comprehensive approach is undertaken using exploratory statistical analysis followed by three descriptive case studies. The paper concludes by recommending action categories for walkability/bikeability enhancement for the city of Syracuse as well as similar mid-sized cities.

The Case of Syracuse NY

Syracuse has an historic opportunity to rapidly increase adoption of sustainable transportation alternatives by leveraging more than $80 million invested in multi-modal transportation infrastructure in four projects: the Connective Corridor (Knauss, 2015), the Onondaga Creekwalk (City of Syracuse, 2012), the Centro Transit Hub (Weaver, 2012), and a multi-modal transportation hub at the Syracuse Center of Excellence. Further, the City is implementing an ambitious comprehensive plan that envisions steady expansion of bicycling and pedestrian infrastructure over the next 25 years (City of Syracuse, 2012). The characterization of human-powered mobility in Syracuse is composed of an extensive pedestrian network and small, yet expanding, bicycling network. As part of the Syracuse Comprehensive Plan 2040, improved pedestrian and bicycle infrastructure each have a dedicated plan of study and implementation. At the time of writing this paper, the Bicycle Plan has been adopted while the Pedestrian Infrastructure Plan is not yet complete.

Since the beginning of the Connective Corridor project in 2005, a 2-mile long pedestrian friendly corridor was created from the University Hill neighbourhood to the downtown neighbourhood. The walking improvements consisted of new sidewalks, better street lighting, public seating for resting and enhanced storm water management to keep the sidewalks and intersections from flooding (Knauss, 2015). In addition, the Onondaga Creekwalk is the first multi-use recreational path from the urban centre to Onondaga Lake. A project idea that was conceived nearly fifty years ago and took 11 years to complete Phase I. Phase I finished in 2011 with a 2.6-mile and 13 ft. wide path along Onondaga Creek from Armory Square, a relatively vibrant public space in downtown, to Onondaga Lake. Plans to extend the path south 2 miles from Armory Square to Kirk Park are currently in progress (Creekwalk, 2009).

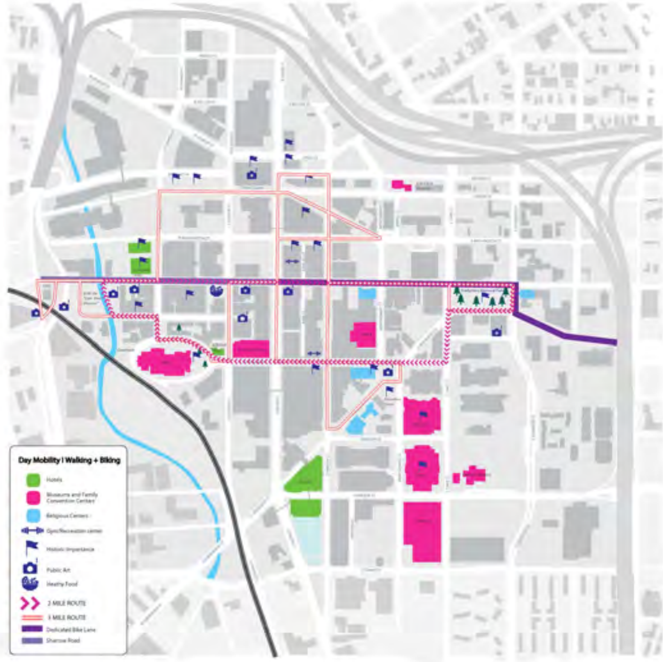

Figure 1. Day time mobility mapping in Downtown Syracuse highlighting human-powered mobility priority routes, as well as relevant activity categories.

Figure 2. Night time mobility mapping in Downtown Syracuse, highlighting night activity amenities and their operating hours. Public transit is highlighted with 5 and 10-minute walking radii from transit nodes.

Bicycling in Syracuse is limited due to the lack of bicycle specific infrastructure. The Syracuse Bicycle Plan proposes to add a total of 65 bike lanes throughout the city. Since 2004, 23% of the Bike Plan has been implemented with most of the improvements being completed in the past five years. The improved bicycle network is projected to increase bicycle mode share. However, this may not be a consistent increase throughout the year with consideration of the harsh winter weather that may alter travel decisions amongst bicyclists (City of Syracuse, 2012).

Figures 1 and 2 show mobility options in downtown Syracuse. Destinations in the day activity map were selected based on different interests during the daytime such as museums, public art, and historic landmarks. Night activities were selected to show destinations with late operating hours such as dining and entertainment locations. For both maps, mobility options were highlighted to show viable alternatives for each time condition and reveal any gaps in mobility modes. The information represented on these maps reflects scenarios with the currently available infrastructure.

Exploratory Research of Mid-sized US Cities

Table 1. Developed database for investigated cities characteristics. Mode share source: DATA USA, 2016. All infrastructure project counts (ped, bike and transit) were retrieved from public works websites for each city.

		Pop. Density (p/mi^2)	Ped. Infra. (No.)	Bike Infra. (No.)	Transit Infra. (No.)	Walk Share (%)	Bike Share (%)	Transit Share (%)	Walk-Score®	Bike-score®	Transit-score®
	Syracuse	5,583	18	4	2	10.4	1.2	8	60	49	n/a
NYS	Albany	4,491	5	6	4	10.4	0.8	3	65	n/a	53
	Buffalo	6,436	6	8	3	6.6	0.9	12	67	54	50
	Rochester	6,133	15	11	8	6.2	1.2	4.4	64	59	43
	Yonkers	11,142	4	4	1	10.6	0	9.5	71	n/a	53
NACTO	Boulder	3,947	25	18	9	10.1	10.5	9.5	58	86	48
	Burlington	4,121	17	5	4	20	5.5	10.4	54	n/a	n/a
	Chattanooga	1,222	13	12	5	2.7	0.4	1.7	29	30	n/a
	Denver	4,044	25	20	13	4.1	2.5	7.4	60	71	47
	Detroit	5,142	6	6	7	1.4	3.3	1.6	55	55	33
	Ft. Lauderdale	4,761	16	15	13	1.7	1	3.7	58	54	39
	Madison	**3,037**	**21**	**58**	**5**	**9.6**	**5.5**	**8.9**	**48**	**73**	**38**
	Minneapolis	**7,485**	**24**	**13**	**21**	**7.8**	**4.6**	**13**	**68**	**81**	**58**
	Pittsburgh	5,540	7	13	6	10.9	2	17.5	61	40	54
	Portland	**4,375**	**28**	**24**	**7**	**5.4**	**7.2**	**11.8**	**64**	**72**	**51**
	San Diego	4,003	36	21	17	1.8	0.3	3	50	46	37
	San Jose	5,600	5	10	9	1.8	1	4.1	50	57	41

In order to inform Syracuse human-powered mobility design and planning praxis, we investigated efforts in four other cities in NY state, as well as twelve motivated cities across the US that joined the National Association of City Transportation Officials (NACTO). Table 1 shows data gathered to enumerate population density, number of pedestrians, bicycle and transit infrastructure projects, transportation mode share as well as the walkscore, bikescore, and transitscore of the 17 investigated cities. A Pearson correlation statistical test was computed to assess the relationship between all factors with no established hypotheses in an effort to explore correlation trends and statistical significance. The correlation measures the strength of the linear relationship between two factors. It is important to note that the sample size is limited, and due to paper scope limitations, we are only reporting significant and trending correlations for mode share and infrastructure project observations.

Mode Share

Transportation mode share is reported for all cities as the percentage of travellers adopting a certain mode of travel. Walk mode share was moderately correlated with transit infrastructure projects ($r = -0.436$, $p < 0.05$) and transit mode share ($r = 0.556$, $p < 0.02$). A stronger correlation was found with transitscore ($r = 0.686$, $p < 0.004$). We also found moderate correlations between bicycle mode share and total number of pedestrian infrastructure projects ($r = 0.45$, $p < 0.036$). Correlations with bicycle infrastructure projects ($r = 0.388$, $p < 0.062$) and public transit mode share were moderate and approaching statistical significance based on the standard cutoff p-value of .05 ($r = 0.386$, $p < 0.064$). A strong correlation between bicycle mode share and bikescore was also observed ($r = 0.707$, $p < 0.001$). Finally, public transit mode share was moderately correlated with walkscore ($r = 0.486$, $p < 0.025$) and strongly correlated with transitscore ($r = 0.711$, $p < 0.003$).

Infrastructure Projects and Initiatives

The number of all infrastructure projects and initiatives related to pedestrians, bicyclers, and transit users over the past decade was tabulated and represented in table 1. Concerning pedestrian infrastructure projects, we found moderate correlations with number of bicycle infrastructure projects ($r = 0.481$, $p < 0.026$) and bicycle mode share ($r = 0.45$, $p < 0.036$), correlations that were approaching statistical significance with bikescore ($r = 0.429$, $p < 0.063$), and strong correlations with transit infrastructure projects ($r = 0.6$, $p < 0.006$). As for bicycle infrastructure projects, moderate correlations were found with population density ($r = -0.415$, $p < 0.06$), and correlations with bicycle mode share were approaching significance ($r = 0.388$, $p < 0.063$).

Case Studies: Madison, Minneapolis, and Portland

Qualitative assessment of all investigated cities was undertaken to rationalize quantitative and exploratory research results. In order to adhere to the paper's scope, we chose three cities to discuss their approach to developing various aspects of human-powered mobility.

Madison, WI

We find the city of Madison comparable to Syracuse based on population counts, city size, the relatively colder climate, demographics and mode-share impacted by the population of a large university within the urban area. For Madison, the majority of pedestrian infrastructure improvements typically include sidewalk repairs, intersection improvements, and filling gaps in the pedestrian network. Two of the initiatives that are worth noting:

- *Pedestrian Flags Initiative: Orange flags are placed at intersections for pedestrians to use to get cars to yield for those crossing.*
- *Madison in Motion: Comprehensive strategic transportation plan that outlines missing gaps in pedestrian network and describes which to prioritize.*

Relatively higher bicycle mode share in Madison is likely attributed to the number of infrastructure projects that improve the network. A total of 58 projects were found, making it the city with the highest number of projects in this study including citywide bike racks, new bike lanes and new cycletracks. Two other to make particular note of are:

- *Citywide Bike Detector Stations: Detectors/sensors placed underground in streets and bikeways that measure bicycle count data.*
- *Acewood Bike Trail Lighting: Improve visibility for night cyclists (City of Madison, 2016).*

Minneapolis, MN

Human powered mobility in Minneapolis is relatively successful especially in terms of bicycling. When compared to Syracuse, Minneapolis is comparably a larger city. However, it was considered in order to investigate how biking in particular, is much more successful despite being a city with cold weather climate and winter precipitation. Some noteworthy pedestrian projects include:

- *Painted curb extensions – These are extensions of sidewalks at intersections to shorten crossing distances and provide refuge for pedestrian.*
- *First Ave. Walking Pilot Project – A temporary sidewalk expansion to evaluate the impacts of providing additional pedestrian space.*

There are several projects for improving bicycle infrastructure in Minneapolis through the means of adding shared lanes, bike lanes and cycle tracks. The Minneapolis Bicycle Master Plan (City of Minneapolis, 2011) outlines the goals for bicycling and how it plans to make it a more viable option through both infrastructure development and policy changes. These strategies are listed as:

- *Education: Giving people of all ages and abilities the skills and confidence to ride.*
- *Encouragement: Creating a strong bike culture that welcomes and celebrates bicycling.*
- *Enforcement: Ensuring safe roads for all users.*
- *Equity: Create an accessible network for all users of different demographics.*
- *Evaluation: Planning for bicycling as a safe and viable transportation option.*

Portland, OR

Although Portland is much larger than Syracuse both in area and population, we considered it for an investigation of how it managed to successfully establish sustainable transportation as a viable option. Since 1998, the Pedestrian Master Plan has been in action improving walking in the city. More recent efforts include Walk There! And Ten Toe Express which provide guided walks and resources to promote walking (City of Portland, 2016).

In terms of biking in the city, a significant number of infrastructure projects exist that are geared towards increasing the number of bicyclists, bicycle mode share, and biking safety. The Portland Bicycle Master Plan adopted in 2010 is a twenty-year plan that sets a vision and goal for bicycling to be a more viable option for traveling three miles, and 25% of all trips are projected to be made by bicycle. To achieve this six key areas were outlined:

- *Attract new riders: Plan and design for people who feel either unsafe or uncomfortable.*
- *Form a dense bike network: Provide an array of route choices.*
- *Increase bicycle parking: Satisfy demand for parking at travel destinations.*
- *Expand programs to support bicycling: Introduce more education programs.*
- *Increase funding for facilities.*
- *Strengthen bicycle policies.*

Discussion

The results we present in this research show interesting relationships that should inform future implementations relevant to human-powered mobility in mid-sized cities. These can be summarized as follows:

Every transit trip starts and ends with a pedestrian trip
Statistical analysis reveals a strong relationship between assessments of walk mode share and pedestrian initiatives with transit mode share and transit initiatives, as well as correlations between transit mode share with both walkscore and transitscore. However, bicycle mode share relates weakly to public transit on all fronts, and beyond that, correlates with pedestrian infrastructure projects only. This finding suggests that walking and bicycling as travel modes should be treated separately in terms of initiatives and assessments. Ped/bike initiatives typically happen at the same time, but their impacts differ. Whereas walking as a mode is strongly linked to transit and should be studied in that context.

If you build it, they will come
Results also suggest that pedestrian, bicycle, and transit infrastructure projects and initiatives are typically related to each other via a positive trend (when one increases, so does the other). This suggests that when a city is planning for human-powered mobility initiatives for all modes other than cars are affected. Interestingly, no correlation was found between pedestrian infrastructure projects and walk mode share, but bicycle infrastructure projects and initiatives relate moderately to bicycle mode share. This finding suggests that for bicycling as a mode share, infrastructure has an influence.

It is not just about the numbers
Although examined cities varied in their priorities, resources and approaches, they share common themes that can be categorized qualitatively. Based on the analysis, categories typically include 1) facilities and infrastructure, 2) educational resources, 3) policy, 4) marketing, 5) financing, and 6) operation and maintenance. It is worth noting that some quantitative assessments may fail to correlate with what they are intended to measure. For example, walkscore did not correlate with walk mode share but instead correlated with transit mode share. This suggests that walkscore may not be effective in assessing walkability due to a process of assessment that is linked to accessibility. However, bikescore and transitscore correlated more reliably with bike mode share and transit mode share, respectively.

Conclusion

Human powered mobility needs across all examined cities vary based on funding resources, climate, and population. Although the number or projects, plans, and programs sum up to a variety of different improvements and efforts, we can begin to categorize them into more broad needs to improve human powered mobility. We recommend that mid-sized US cities, like Syracuse, NY, can address human-powered mobility programming needs through:

1. *Facility upgrades: Design and infrastructure improvements to repair, beautify. and improve safety for pedestrians and bicyclists as separate modes.*
2. *New facilities: Addition of facilities for pedestrians linked to transit, or bicycle network to focus on cyclists. This could be in the form of new lanes, paths, etc.*
3. *Education resources: Digital or physical resources for self-learning information on walking and biking based on successful case studies.*
4. *Education programs: Active programs provided and led by advocacy groups and organizations for communities to help promote human-powered mobility.*
5. *Policy changes: Improve policies to benefit pedestrians and bicyclists making them a priority as well as making travel to destinations more fun, safe, and convenient.*

6. *<u>Outreach Marketing</u>: Increase awareness of walking and biking improvements around the city together with the benefits of utilizing the network.*
7. *<u>Funding Resources</u>: Seek funding from a variety of sources as well as redistribute funding toward human-powered mobility services.*
8. *<u>Action Planning</u>: Develop plans for maintaining the active transportation networks as viable options year-round.*

Future research should address the limitations of this paper and pursue quantitative assessment of education and policy initiatives in different cities and scenarios. Furthermore, other case studies should be investigated to inform success in sustainable mobility adoption.

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Design to Thrive

Upgrading urban highways: issues and negative impacts based on a case study of Sadr's Elevated highway

Ehsan Ranjbar[1] and Seyed Navid Mashhadi Moghadam[1]

[1] Faculty of Art and Architecture, University of Tarbiat Modares, Tehran, Iran.
Correspondence email navid.m.moghadam@hotmail.com;

Abstract: Transportation as the vessel of the world has always a significant role in urban functions. This important part of urban big picture sometimes struggles with environmental aspects. By highlighting its goal of accessibility and economic features, may conclude to damage urban environment. In recent years, Tehran municipality decided to upgrade one its own highway to an elevated highway called Sadr's Elevated Highway. This study aims to evaluate this urban phenomenon from the environmental prospect. For this purpose, firstly, this paper reviews a body literature around environmental impact assessment (EIA) then secondly argues about urban highways, expressways and elevated highways through an epistemology of why urban highways are important? And does the true time arrive to eliminate this subject from urban structure? After that, this study assesses environmental impacts of Sadr's Elevated Highway as an empirical study based on two distinguish models. The first model is an integrated model and its functionality based on weighting and matrixes and second one is a ranking model also known as Multi-criteria decision analysis called VIKOR. Results of this paper showed the elevated highway in case of Tehran is a mistake in types of urban transportation developments form prospect of urban environment sustainability.

Keywords: Elevated Highway, EIA, Urban, VIKOR.

Introduction

In 2013, Deputy of Technical & Development Affairs of Tehran Municipality constructed second level of a highway which makes the old one highway as a new elevated highway. This is a personal vehicle oriented action which generally encourage citizens to use their own car travel around the city. Is this a sustainable architecture in urban scale? To answer this question it is needed to apply an Environmental Impact Assessment. The first phenomenon influencing the thinking of Environmental Impact Assessment was the publication of Silent Spring by Rachel Carson in 1962, which brought the attention of American society on the living environment and created some concerns about neglecting environment vulnerability during the development projects in the late 60's (Overseas Environmental Cooperation Center, 2000). In 1969, According to the National Environmental Policy Act (NEPA), sustainable environmental impact assessment took legal position in North America (Ogola, 2007). Based on the NEPA 1969 act, all large-scale projects like constructing a dam or mine should have environmental impact assessment before initiation of a project (Partidario, 2007).

Through the 1960s, two key factors increased attention to the local effects of and public participation in urban highways and public transit construction. The first was operating the federal-state system of highways, which had significant effects on local resources and neighborhoods, and the second factor was raising awareness of issues such as protection of the environment and the marginalization of the poor / minority population in urban communities' thoughts (Weiner, 1992). The federal highways' law (1967) set an independent organization for monitoring the environmental impacts of construction of the highway were required, as well as citizens on the basis of this law could have their opinions in relation to social and environmental issues surrounding by the proposed highway projects. But the meeting between public officials and highway construction projects in the final stages of the development project was held. The biggest step through the process of construction of the highway is divided into two parts in late 1969 and early 1970, with the adoption and implementation of the national environmental policy act (NEPA). According to the national law that reflects the concerns of the previous decade, In the first phase of the project, there should be a report of assessing the possible effects (both macro and micro) of development projects on the environment, local communities and the economy and secondly after the adoption of the first phase by the public and local stakeholders, the project must be divided to multiple phases due to reducing its own negative impacts (Hughes, 1998). This process quickly spread around the world and played a significant role in reducing the environmental impact of highway development projects. Following table is a summary of five stages urban highways passed from 1911 until the contemporary century.

Table 1. History of urban highway developments approaches

Stages	Describe
First stage: Birth of highway	The first Highway constructed in 1911. Prior to influence of economic approach in the 1950s it can be considered the first course of highways' construction between 1911 and 1950. In this course as John Dewey in his the most important theory states "learning by doing" is the main approach that consciously or unconsciously applied by the authorities in highway construction (Ord, 2012; Plummer, 2005).
Second Stage: growth of highways	The second period placed between 1950 and 1962. What distinguishes this period from before and after is appearance of economic science and economic performance of cities. This economic approach tried to maximize speed and number of citizens and goods transportation. The root of such thinking as stated earlier in Chicago Transportation Studies (CATS) can be seen clearly (Plummer, 2005).
Third Stage: respond to public thoughts	In the period of 1962 to 1970 as well as with rising local communities' awareness of the negative effects of the highway, the economic approach founded by the study of the Chicago Transit faced with some. The changes were responses to the protests of local communities, with the aim of taking into account environmental issues in construction transportation projects of Metropolis. As a result of those changes some organizations founded to monitor large-scale projects (such as freeways and subways) in order to predict and prevent damage to the natural environment during the preparation of development plans and programs (DYBLE, 2007; Mohl, 2002).
Fourth Stage: Appearance of Environmental Impact Assessment	In 1970, with mandatory of environmental impact assessments for development projects, a new framework conducted for highway development projects, which authorities must prepare a report of environmental impacts of their projects and published for the public. In this report, impacts of social, economic and environmental of a

	development project on the target population should be mentioned in all phases of construction, including pre-construction, during construction and operation phase. Meanwhile, discount strategies and plans for mitigation of negative impacts should be included in it (Overseas Environmental Cooperation Center, 2000).
Fifth Stage: Death of urban highways	This stage refers to recent approach to urban highway developments but has lack of enough comprehension to be an inviolable theory. This theory argues about the removal of urban highways; however, in recent years a lot of researches done on this issue or are in progress. For example, one of the most important research into this field is the study of Bocarejo, LeCompte, and Zhou (2012) in their magnificent book titled "Life and Death of urban highways" in which they argue about the reasons for the removal of urban highways, viable alternatives to the removed highways and some cases of successful elimination of highways in the United States America and other countries such as South Korea and Colombia. Although an overview of existing studies on the removal of urban highways shown that highways' elimination happened in certain circumstances, but in most cases occurred with the wishes and demands from local communities. Although admission to this lack of cohesion just needed to more contemplate, however, it shows that local communities in most developed countries, and few developing countries reached to high level of awareness and understanding of environmental issues in their surrounding living area (Bocarejo et al., 2012).

In the late twentieth century, international institutions (including the World Bank and the Asian Development Bank), and different countries conducted different frameworks and guides for environmental impact assessment. According to different contexts of highway development projects, there are differences in dimensions and criteria, which should assess in the process of EIA. For example, the quality of urban design and attention to viability in the context of environmental impact assessment in the United States of America is important, and the cultural effects and avoiding interference in the city dynamic are one of the late criteria considered in EIA in Great Britain (Department for Communities and Local Government, 2006). Table 2 shows selected dimensions and criteria based upon the context of this paper case study.

Table 2. Dimensions and Criteria used in this study

Dimensions	Criteria
A. Social environment	*A1. Social justice*
	A2. Safety and Security
B. Physical environment	*B1. Relocation of houses*
	B2. Land acquisition
	B3. Traffic Management
	B4. Accessibility

C. Visual environment	*C1. Urban landscape and visual appearance*
	C2. City image and the sense of belonging
D. Economic environment	*D1. Land price*
E. Ecological environment	*E1.Air pollution*
	E2. Noise pollution
	E3. Energy
	E4. Environmental damage

Method

The first method using in this study introduced by Hao Cai (2011) which in this method, the whole road will be divided into several sections, and giving the different weight to each zone, and each zone with the first-class indexes and the second-class indexes, with Analytical Hierarchy Process (AHP) and Delphi software to calculate the weight of different indexes.

The Second Model to evaluate environmental impacts in this paper is the VIKOR model. The VIKOR method is a multi-criteria decision making (MCDM) or Multi-criteria decision analysis method. It was originally developed by Opricovic (1998) to solve decision problems with conflicting and non-commensurable (different units) criteria, assuming that compromise is acceptable for conflict resolution, the decision maker wants a solution that is the nearest to the ideal, and the alternatives are evaluated according to all established criteria. VIKOR ranks alternatives and determines the solution named compromise that is the closest to the ideal. The purpose of using VIKOR method for this study is the VIKOR method checks; whether the top-ranked alternative can be considered better enough than the others by testing acceptability advantage and acceptable stability conditions. If any of these two conditions is not satisfied, then VIKOR proposes a set of compromise solutions based on maximum group utility of majority and minimum individual regret of the opponent. Furthermore, another reason for employing the VIKOR method is because this technique is mainly based on the particular measure of closeness to the ideal solution, and it focuses on selecting the best choice from a set of feasible alternatives in presence of mutually conflicting criteria by determining a compromise solution (Shankar Chakrabortya & Chatterjee, 2013).

Case Study

Sadr's Elevated Highway (SEH) is a freeway in northern Tehran, Iran. This freeway runs west from the Modarres Expressway in Gholhak neighborhood east through Gheytarieh, Doulat, Darrous, Chizar, and Ekhtiariyeh, at which point it crosses Pasdaran Avenue and becomes Babayi Expressway. Sadr Expressway serves the dual purpose of connecting the northeastern suburbs of Tehran to the business center, as well as functioning as an arterial road between the capital and the north and northeast of Iran. This bridge consists of the main bridge with 22.7m width and 6 km length and over than three set rams with 5km length at all.

Figure 1. Sadr’s Elevated Highway

Results

The first method: based on Table 3, the Sadr’s Elevated Highway (SEH) has negative impacts in the ecological and visual dimensions but positive impacts in the economic, physical, and social dimensions. The overall physical impact of the SEH in all of its four sections is plus 1.61, which is its strongest point, while its impact in the ecological dimension is minus 2.39, which is its largest negative impact among the various dimensions and, therefore, is its most important shortcoming. Moreover, the visual dimension of the SEH has the negative impact of minus 1.31, which is its second most important negative impact. The social and economic dimensions with plus 0.42 and plus 0.21, respectively, are its second and third most important positive impacts. Therefore, the SEH has positive impacts in three dimensions and negative impacts in two dimensions.

Table 3. First Method final results

Dimensions	First Section of SEH	Second Section of SEH	Third Section of SEH	Fourth Section of SEH
Social environment	0.04	0.1	0.23	0.06
Physical environment	0.12	0.39	0.87	0.23
Visual environment	-0.1	-0.32	-0.71	-0.18
Economic environment	0.02	0.05	0.11	0.03
Ecological environment	-0.18	-0.58	-1.3	-0.33

The second method: Table 4 presents the distance between the actual performance and the best and worst case performance of the SEH with respect to the impacts of each criterion. In other words, the value of Si for each criterion represents the distance between the actual status of the SEH and that of a highway in the best case scenario. For example, as shown by the calculations in Table 4, the ideal Si value for the local integration criterion is zero, while its value for the SEH is 0.019; i.e., there is a distance of 0.019 units between the impact of the SEH and that of a highway in the best case scenario in relation to the local integration criterion. However, this distance by itself does not signify a low or high value. Therefore, the Si values for the worst and intermediate case scenarios must also be calculated so that the distance between the impacts of the SEH and those of a highway in the best case scenario can be tangible, and the status of the SEH can also be determined compared to those of the intermediate (average) and worst case scenarios, by considering the best, the intermediate and the worst case scenarios.

Table 4. Results of second method

Criteria	Ideal	SEH	Mediate	Worst	w	Ideal	SEH	Mediate	Worst	Ideal	SEH	Mediate	Worst
	dij	**dij**	**dij**	**dij**		**si**	**Si**	**Si**	**Si**	**Ri**	**Ri**	**Ri**	**Ri**
a1	0	0.493	0.500	1.000	0.038	0.000	0.019	0.019	0.038	0	0.126	0.089	0.178
a2	0	0.449	0.500	1.000	0.074	0.000	0.033	0.037	0.074	**Si**	**Si**	**Si**	**Si**
b1	0	0.551	0.500	1.000	0.052	0.000	0.029	0.026	0.052	0	0.532	0.5	1
b2	0	0.462	0.500	1.000	0.065	0.000	0.030	0.032	0.065	**S***	**S***	**S***	**S***
b3	0	0.300	0.500	1.000	0.053	0.000	0.016	0.026	0.053	0	0	0	0
b4	0	0.417	0.500	1.000	0.043	0.000	0.018	0.022	0.043	**S^**	**Su^**	**Su^**	**Su^**
c1	0	0.649	0.500	1.000	0.063	0.000	0.041	0.031	0.063	1	1	1	1
c2	0	0.537	0.500	1.000	0.043	0.000	0.023	0.021	0.043	**R***	**R***	**R***	**R***
d1	0	0.500	0.500	1.000	0.035	0.000	0.017	0.017	0.035	0.178	0.178	0.178	0.178
e1	0	0.709	0.500	1.000	0.178	0.000	0.126	0.089	0.178	**R^**	**R^**	**R^**	**R^**
e2	0	0.525	0.500	1.000	0.110	0.000	0.057	0.055	0.110	0	0	0	0
e3	0	0.553	0.500	1.000	0.133	0.000	0.074	0.067	0.133	**Q**	**Q**	**Q**	**Q**
e4	0	0.457	0.500	1.000	0.114	0.000	0.052	0.057	0.114	0	0.621	0.5	1

Thus, as shown in Table 4, the impact of the local integration criterion with the value of 0.019 is equal to that of the intermediate case scenario. Moreover, the security impact of the SEH with the value of 0.033 is slightly smaller than that of the intermediate case scenario; i.e. it is closer to that of the best case scenario. However, with respect to the criterion related to the destruction of the original local structure, the value for the SEH (0.029) is 0.03 units higher than that of the intermediate case scenario; i.e., it lies somewhere between the worst case and intermediate case scenarios. As for the impact of the traffic management criterion also, the SEH with the value of 0.03 and a distance of 0.002 units from that of the intermediate case scenario, is placed between the intermediate and best case scenarios. The SEH (with the value of 0.016) has a greater distance from the intermediate case scenario with respect to the criterion of the land seizure impact and is closer to the best case scenario. Furthermore, with respect to the criterion of impact on access, the SEH lies between the intermediate and best case scenarios. As for the two criteria of the impacts on “urban landscape and visual appearance” and “city image and the sense of belonging,” the performance of the SEH is placed between those of the intermediate and worst case scenarios. In the criterion of the impact on “land price,” the performance of the SEH is equal to that of the intermediate case scenario, and in the criteria of the impacts on “air pollution”, “noise pollution”, and “energy,” the performance of the SEH lies between those of the worst case and intermediate case scenarios.

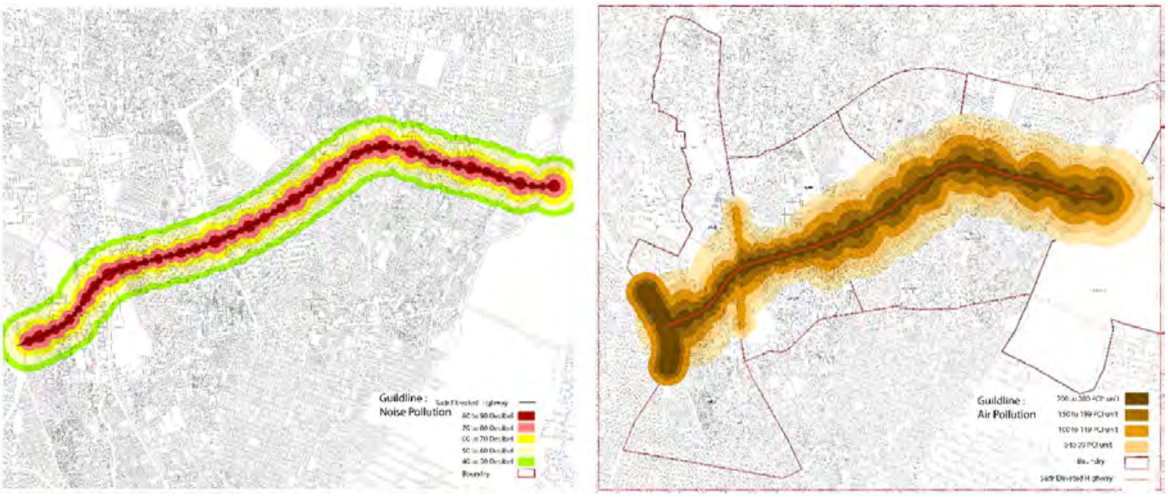

Figure 2. Noise and Air Pollution after construction of elevated highway.

Figure 1. Noise and Air pollution map for Sadr’s Elevated Highway 2016. PCI*: percutaneous coronary intervention.

Finally, the Q index, the values of which for the worst, the intermediate, and the best case scenarios are listed in Table 3, shows the distance between the performance of the SEH and that of the best case scenario. The value of the Q index (0.621) indicates that the SEH is placed between the worst and the intermediate case scenarios with respect to its environmental impacts. To better understand the final score of the SEH, the formula below is used to calculate the value of the Q index for the performance of the SEH in the interval from zero to 10, with zero being the Q value for the worst case scenario and 10 the Q value for the best case scenario:

$$Final\ Score\ of\ SEE = (1 - Q_{\mathrm{SEH}})\times 10 = (1 - 0.621)\times 10 = 3.8$$

Therefore, the score for the SEH is 3.8 out of the perfect score of 10.

Conclusion

The results from this study showed an elevated highway in this case Sadr’s Elevated Highway has significant negative impacts in ecological dimension, including air and noise pollution and energy-consuming parameters; this means regarding to creating sustainable structure for urban development, upgrading Sadr’s Highway to an elevated one is a failure action. Due to final score of VIKOR method in this paper, SEH is also a fail experiment; however, if any changes occur on the number of criteria, the result may have been different from this study result but 3.8 as a score between 0 and 10 is very low and completely beneath of middling scenario. Therefor this study is first step to consider this fact that elevated highways/expressways aren’t perfect alternative to respond to vehicle demands in urban transportation. There could be more investigations on this subject to find an answer is the truly time arrived for removing this structure from the urban face?

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Towards an integrated urban design approach for a sustainable modal shift: Presenting insight from design practices

Maja Karoline Rosenkilde Rynning[1,]

[1] Laboratoire Matériaux et Durabilté des Constructions de Toulouse (LMDC), Institute des Sciences Appliquées de Toulouse (INSA Toulouse), University of Toulouse, Toulouse, France
maja.karoline.rynning@gmail.com

Abstract: Reducing greenhouse gas emissions from urban mobility are a major challenge for cities, in part because of its importance for everyday life. Promoting sustainable modes through neighbourhood design is an interesting strategy. However, uncertainties in the scientific evidence on neighbourhood-built environment and modal choices complicate its use in design practices. Disparities between research and practice further hinder knowledge-transfer. The experience-based knowledge of urban design professionals could be a source for new insights; preliminary investigations gave promising results. Further investigations included surveys and interviews in Norway and France. Survey-elements are presented here, compared in part to current scientific evidence. Results from these investigations, in combination with scientific literature, provide the basis for a framework for an integrated urban design approach. Linking modal choices to urban design qualities, it weaves together evidence-based and experience-based knowledge for a holistic approach; a step strengthening mitigating efforts upon urban mobility.

Keywords: Urban design, Modal choice, Experience-based knowledge, Urban mobility, Mitigation

Introduction

Urban mobility represents a multifaceted problem for cities. It is essential for a city to function (Ascher, 1995; UN Habitat, 2013), but produces greenhouse gas emissions (GHG-emissions) that leads to global warming and climate change (IPCC, 2014; New Climate Economy, 2014). Reducing mobility-related emissions (mitigation) calls for a variety of approaches, and for interdisciplinary collaborations. One strategy is to promote a sustainable modal shift towards zero- and low emission mobility modes[1] (New Climate Economy, 2014). An on-going doctoral thesis (Rynning, foreseen 2017) explores how to achieve such a modal shift through urban development at the neighbourhood scale (i.e. urban design), by combining experience-based knowledge (from practice) and evidence-based knowledge (from research).

There is a reciprocal relationship between the urban built environment and mobility behaviours (Næss, 2006). How a city is planned and designed influences how people move around in it, and vice versa. Consequently, integrated land-use and transport planning is an important mitigation strategy at the city scale (Tennøy, 2012). At the neighbourhood scale however, a similar approach appears less explored. One explanation is a significant knowledge-gap in literature regarding the neighbourhood-built environment and modal

[1] Per today these include primarily walking, cycling, and public transport (assuming it runs on low- or zero-emission fuels, and has a high level of occupancy) (New Climate Economy, 2014).

choices (Krizek et al., 2009; Næss, 2012); making it difficult to provide urban designers with concrete knowledge on how to promote sustainable mobility modes through urban development (Krizek et al., 2009). More insight is necessary, perhaps from exploring other sources. Furthermore, disparities between research and design-practice often complicate the use of scientific knowledge in development projects (Eliasson, 2000; Dubois, 2014). A reinforced dialogue between research and practice is needed in order to strengthen interdisciplinary co-operations and reciprocal knowledge-transfer (Rynning, 2016).

This paper explores the knowledge and experience of urban design practitioners for new insights into the reciprocal relationship between neighbourhood-built environment and modal choices. Preliminary investigations through a series of workshops implied that mobility has a central role in a development project (Rynning, 2016); integral to assure good living contexts for urban dwellers (ibid). To further explore, surveys and interviews were conducted with urban practitioners in France and in Norway. This article focuses on survey-findings, compared to previous findings and to relevant scientific evidence. These enquiries also provide an improved understanding of the methods and practices of urban design professionals; insights which can enhance reciprocal knowledge exchange research-practice – key to reinforcing adaptation and mitigation efforts through urban development (Eliasson, 2000; Tennøy, 2012; Dubois, 2014).

Theoretical framework: The built environment and mobility behaviour

Mobility behaviours are influenced by contexts (physical, built environment, social, cultural, economical, etc.), and by personal preferences and capacities (Næss, 2006; Krizek et al., 2009). It tends to be highly different from one person to another, though common traits can be found for segments of a population, for instance age-groups (children, elderly, etc.) (Bull and Bauman, 2007). Krizek and Forsyth (2009a) found presence of pedestrian infrastructure to be critical for elderly's decision to walk, while able-bodied adults relied less upon this. Similar tendencies were found regarding experienced and inexperienced cyclists and the presence of cycling infrastructure (ibid). Neighbourhood-built environment is particularly important for walking and cycling (Saelens and Handy, 2008; Krizek et al., 2009). By correlation, it influences transit use as well, as people mostly walk or cycle to and from transit stops (Mees, 2010). Several built environment elements have been found to influence modal use at the neighbourhood scale, for instance sidewalk width, number of intersections, and view-lines. (Alfonzo, 2005; Ewing et al., 2016). However, which factors influence the most remains unclear (Krizek et al., 2009). In part, because people's experience and perception of a built environment depends on context, physical as well as social and personal (Cho and Rodriguez, 2015). Based on these findings, a holistic strategy might be more beneficial, directing the focus towards the kinds of urban environments or scapes a combination of factors and elements create. One example are streetscapes – the space between buildings (Gehl, 2010; Ewing et al., 2016). Different built environments can be perceived as more or less welcoming for walking and cycling, thereby encouraging or discouraging their use (Stefansdottir, 2014). Three built environment-components have been identified as particularly influential upon modal choices: *Destination* (location of a trip's objective), *Availability* (if a mode is compatible with a trip), and *Annoyance* (barriers for using a particular modal choice). They are interdependent, and the built environment's influence on a modal choice is the sum of all three. Together they form a holistic framework, linking modal choices to urban environments, scapes, and to qualities. Such a framework can render scientific evidence more relatable and useable for urban design practitioners.

Urban qualities such as human scale, legibility, and connectivity, are often expressed by urban practitioners as particularly important for creating good, urban living contexts (Gehl, 2010; Rynning, 2016). Through the holistic framework, they can be linked to a potential influence upon modal choices as well. This can strengthen urban design as a strategy to promote a sustainable modal shift in order to curb mobility-related GHG-emissions.

Method: Interview and survey design

Studies have shown that workshops, interviews, and surveys are particularly interesting for exploring the experience-based, often tacit, knowledge of design professionals (Schön, 1983; Lawson, 1993; Skogheim, 2008; Dubois, 2014; Kirkeby, 2015). In the context of the doctoral thesis all three have been employed; the focus here in on the survey results. The workshops, a simulated design situation, served as a case study of urban design practices, and provided initial insights (Rynning, 2016). Through the survey, workshop observations regarding mobility in a design process were pursued in a more quantitative manner. It also enquired how practitioners relate urban qualities to modal choices, based on findings from the literature (see above). The targeted respondents were primarily professionals with an education within Architecture, Landscape Architecture, Urban Planning or Design. The survey was held in Norway and France, from November 2016 to January 2017, using SurveyMonkey. Respondents were recruited via social media forums for professionals, and through personal invitations. The analysis comprised both qualitative and quantitative methods. The questions were all close-ended, asking respondents to rate the influence of an element, or to what extent they agreed to statements (four grades, no neutral). A rating average was calculated with coefficients, e.g. 2 = strongly agree, 1 = agree, -1 = agree to some extent, -2 = disagree. The results are presented in the tables below, total rating average for Norway and France combined.

Results

A total of 112 practitioners commenced the survey and 71 (63,4%) completed it, of which 67 (59,8%) provided information about their practice. The majority of Norwegian respondents had 10-20 years of experience (15 of 31), none more than 30 years. Most of the French respondents had 0-5 years of experience (15 of 36), the rest were quite evenly spread between 5 to 30 years of experience. The respondents were also asked about educational background, for which several choices were possible, as this tends to vary for urban practitioners. Architecture (39 of 67) was the most common education, followed by Urbanism (26 of 67), Planning (17 of 67), and finally Landscape Architecture (10 of 67). A few had other backgrounds, for instance Sociology (2 of 67), Geography (2 of 67), or Engineering (2 of 67). The most common combination was Architecture and Urbanism (17 of 67).

Mobility in an urban design process

This part primarily tested the workshop observations. The vast majority of the respondents (101 of 109) consider the daily mobility of inhabitants in a project. Some only in the site analysis, but most implement measures and solutions directed towards daily mobility (25 versus 72 of 97). The survey asked what considering daily mobility in the site analysis contributes to (Table 1), likewise for the implementation of mobility solutions and measures (Table 2). Exploring elements that influence the choice of mobility solutions and measures, respondents were asked to choose the three most influential from a list of suggestions (Table 3).

Considering mobility in the site analysis contributes to (87 responses)	Analysis (19 resp)	Analysis+Solution/Measure (66 responses)
1. Link the project to the urban context	1,63	1,52
2. Understand the inhabitants' use of the neighbourhood	1,47	1,69
3. Identify challenges and issues beyond project description	1,37	1,37
4. Establish an idea, a concept	0,79	0,90

Table 1 What mobility in the site analysis contributes to, ranked score (min. -2, max. +2)

Implementing mobility solutions/measures in a project contributes to	
1. Facilitate walking and cycling	1,66
2. Facilitate the use of public transport	1,52
3. Link the project to the urban context	1,44
4. Introduce measures to reduce the inhabitants' use of cars	1,39
5. Structure/shape the neighbourhood	1,38
6. Create an identity to reinforce the inhabitants' sense of belonging to the neighbourhood	0,86
7. Establish an idea, a concept	0,73

Table 2 What implementing solutions/measures contributes to, ranked score (min. -2, max. +2)

Elements that influence choice of mobility solutions/measures (%)	
1. Existing and potential access to area (street network, access to public transport, active mobility infrastructure, etc.)	81,0
2. Existing structure, urban fabric and form	55,6
3. The program (mixed use, dwelling density, parking solutions, public space, etc.)	50,8
4. The physical context (local climate, vegetation, topography, etc.)	39,7
5. The client's objectives for daily mobility (facilitate public transport, reduce n° parking spaces, space for various modes, etc.)	33,3
6. Society's targets of reducing traffic volume growth	28,6
7. The economical, social, and cultural context	14,3

Table 3 What implementing solutions/measures contributes to, ranked score (min. -2, max. +2)

The survey confirmed that mobility has a central and structuring role in an urban design process, as was seen during the workshops. According to the respondents, in a site analysis mobility contributes to link a project to its urban context. It provides an understanding of both context and site, and a broader comprehension of the project. Implementing solutions and measures is understandably done to act upon mobility, but also aids the practitioner in establishing a relation between a neighbourhood and its urban context. Examples of this were observed in the workshops, where participants used pedestrian infrastructures to interrupt existing barriers (e.g. a large road) between a project site and its surroundings. Survey respondents further reported that mobility solutions and measures contribute directly to the design of a neighbourhood, for example its shape and structure. Similarly, in the workshops prioritising pedestrians had important influence upon the street network. Elements that influence choice of solutions and measures appear in line with the role accorded to mobility in a design process. Context, in a broad sense, influence choice of solutions and measures the most, in particular immediate and surrounding context (1., 2., 4., Table 3). This is in line with findings from literature. The influence of built environment elements on modal choice depends on urban and physical context. This also shows the importance of existing context for urban practitioners' design actions, especially mobility structures and systems. The program and the client's objectives are also reported as having some influence (3., 5., Table 3), indicating the importance of such constraints for promoting or limiting mobility modes through urban design. Finally, mobility solutions and measures were said to contribute somewhat to creating an identity for a neighbourhood. This might be related to the design of public places. In the workshops, good public places with a clear usage were said to encourage pedestrian activity within a neighbourhood, important to establish social cohesion through encounters among inhabitants. Vice versa, prioritizing pedestrian and cycling activity was a means to ensure good public space, illustrating thus the reciprocal relationship mobility/built environment design.

Built environment and modal choices

Respondents were asked to rate the influence of the urban qualities in Table 4 on the use of mobility modes. These are urban qualities often related to the quality of living contexts (Carmona, 2010; Gehl, 2010).

URBAN QUALITIES AND MODAL CHOICE (68 responses)	**Walking**	**Cycling**	**Public transport**
1. Connectivity - Connections between streets, pedestrian networks, etc. within and/or between several neighbourhoods	1,79	1,62	0,49
2. Legibility - How easily one can recognize and understand a neighbourhood, for instance to orient one-self	1,76	1,22	-0,01
3. Human scale - Dimension of built environments relative to human dimensions (e.g. street width, block size)	1,63	0,54	-0,62
4. Enclosure - To what extent buildings and other elements define and shape spaces	1,53	0,44	-0,57
5. Transparence – The possibility to see what goes on at the end of a street and past it, e.g. human activity or particular buildings	1,26	0,50	-0,71
6. Complexity - How a rich variety of buildings and other elements create a diverse visual impression	0,85	0,21	-0,97
7. Coherence – To what extent the built environment creates an overall impression, e.g. through shapes or facades	0,72	0,12	-1,03

Table 4 Survey results regarding urban qualities and modal choices

Connectivity was reported as most influential for both walking and cycling, and for the use of public transport. This is likely related to the link between connectivity and distance. Studies have found that actual and perceived distance is important for modal choice, especially walking and cycling (Krizek et al., 2009). A high level of Connectivity can reduce the distance to cover by breaking up urban blocks. This can also increase the range of route choices for a trip, allowing a person to adapt a trip to their modal needs, for instance choosing a pedestrian-friendly route. Connectivity is to some extent related to *Human scale*, as a high level of Connectivity tends to produce smaller blocks divided by streets and paths. However, Human scale was reported as little influential upon transit use, so it is possible the respondents relate it more to the perception of a pedestrian-friendly environment. Connectivity is a result of the structure and shape of a neighbourhood. These are elements that according to the respondents, implementing mobility solutions and measures can contribute to. Moreover, Connectivity can assure connections between neighbourhoods, also related to the consideration of mobility in a design process. This illustrates the reciprocal relationship between mobility-related actions and objectives in a design process, and the multifaceted role of mobility in a design process. *Legibility* was also reported as influential for all three mobility modes, although most importantly for walking (-0,01 for transit use indicates an approx. 50/50 split on level of influence). It is particularly important for orienting one-self in an environment, for instance via sight lines that allows a person to easily see further ahead (Lynch, 1960). Legibility is related to Transparence and Connectivity. The level of the latter can influence sight lines and the possibility to see what goes on beyond a street (Transparence), which can contribute to reducing the experience of distance (Gehl, 2010). Transparence in itself was given less influence on modal choice then Connectivity and Legibility. This could indicate that for practitioners, actual distance (Connectivity) is more important then perceived, and that Legibility influences modal choice in ways that could be further pursued. Finally, *Complexity* and *Coherence* were said to be somewhat influential for walking, a bit less for cycling, and not much for transit use. These urban qualities are most likely more important for visual experiences and perceptions of a built environment, then for physical aspects such as distances. That they are given a lower level of influence is therefore understandable, although they are not entirely un-influential. The relationship between these qualities and other aspects of a neighbourhood, such as quality of public places, is an interesting aspect for future analyses.

Discussion

Mobility is integral to city life (Ascher, 1995; Gehl, 2010). It is therefore not surprising that it holds an important position in an urban design process. The surveys, combined with the previous workshops, provided further insight to this. Mobility has a multifaceted function in a design process; it influences and is influenced by design actions. Considering mobility in a design process was related to the overall, physical design of a neighbourhood, and to creating perceptual characteristics. It also contributes to identifying issues beyond a project description. Schön (1983) refers to this as a practitioner identifying what a problem "really is", and finding a way to properly "frame it", displaying an understanding of urban development projects as societal problems (Rittel and Webber, 1973). Through a city's many interdependencies, projects are influenced by and influence aspects beyond their limits. This was equally seen in the workshops, where a reported lack of social cohesion was an important issue. Interestingly, encouraging walking within the site was seen as a contributing remedy to this. Thus underlining the multiple functions of mobility for the quality of a neighbourhood as a living context. During the workshops mobility appeared to be seen as a function to resolve, and simultaneously as a means to achieve/resolve other objectives and issues. The results from the survey seem to confirm this observation, providing an interesting aspect for further developing the holistic framework (see above).

The survey results indicate a holistic approach to mobility in an urban design process, in line with findings from literature and observations from the workshops. According to planning literature, an improved living context for urban inhabitants is a common, 'global objective' (Madanipour, 2006; Carmona, 2010; Gehl, 2010). This was seen in the workshops, where participants displayed a holistic approach to the project at hand (Dubois et al., 2016). Every action or solution for a particular issue was evaluated iteratively in light of its potential effect on the totality of the project. Illustrating an understanding of the interdependencies and connections between elements of the built environment. Furthermore, win-win solutions were often employed, to resolve or to achieve several issues/objectives at once. For example when establishing urban qualities expressed as important for creating "a neighbourhood feeling", but also for promoting walking: *porosity, transparency, visibility,* and *openness* (Rynning, 2016). The survey responses similarly showed that mobility solutions and measures are implemented to act upon mobility, and to advance the design of a neighbourhood.

Combining responses on the role of mobility in a design process with urban qualities said to matter for modal choices, might indicate the kind of qualities or scapes practitioners aim for when implementing mobility solutions and measures. Integrated in to the holistic framework in progress, this could further the understanding of the relationship between the built environment and modal choices. The respondents related the suggested urban qualities more to walking and cycling then to transit use. However, as explained previously, walking is a part of most transit trips, and so by correlation these qualities should have a certain influence on transit use as well. In the suggested framework, Destination represents the influence of the built environment at the end of a trip. If that built environment does not support or invite to walking, it can contribute to a person choosing to drive rather then public transport, despite a sufficient transit offer (Mees, 2010). Promoting sustainable mobility behaviours therefore requires a holistic take on a trip, from beginning to end. As practitioners have a holistic approach to urban design projects, there are evident profits from integrating evidence-based and experience-based knowledge. As an example, combining the empirical findings with scientific evidence can contribute to render the connection neighbourhood urban qualities/transit use more apparent for practitioners, making them more aware of the potential influence of their design actions. Together, this could help address the 'last mile'-issue, an important barrier for transit use (UN Habitat, 2013).

Conclusions and future perspectives

Through the results from the empirical enquires so far, the experience-based knowledge of urban design practitioners has provided interesting insights in to the relationship between the built environment and mobility behaviours; insights complementary to that of research. The findings emphasize the importance of a holistic approach to urban development, and to the mitigation of mobility-related emissions. The experience-based knowledge contributes to situate mobility within the totality of an urban development project, linking it to the overall goal of an improved living context. Thereby contributing to identifying more efficient solutions and measures for promoting sustainable mobility modes, and to bridge current knowledge-gaps. The findings also show that urban design can be a strategy towards a sustainable modal shift. Mobility is integral in a city's functioning, and thus integral in people's way of urban life. A sustainable modal shift therefore requires important changes on several levels. The built environment can contribute by facilitating the use of sustainable modes, while limiting GHG-emitting ones; urban design practitioners display knowledge on how to do so. As mobility has a central and structuring role in a project, adding mitigation as an additional objective seem quite possible. To further this, a framework for an integrated urban design and mobility approach is currently being developed, based on evidence-based knowledge from research and experience-based knowledge from practitioners. Moreover, the framework can reinforce the dialogue between research and practice by translating scientific evidence to urban design practices and vice versa, thereby strengthening a much-needed reciprocal knowledge-transfer.

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Design to Thrive

Wellington- the role of transport in creating "the coolest little low-carbon capital"

Rehan Shaikh[1], Robert Vale[1] and Wajid Shaikh[2]

[1] School of Architecture, Victoria University of Wellington, Wellington, New Zealand.
[2] Quaid-e-Awam University of Engineering, Science & Technology, Nawabshah, Pakistan.

Abstract: Transportation is a basic need, but currently it is powered by fossil fuels which add CO_2 to the atmosphere. It will be difficult to achieve reduced CO_2 emissions in cities which rely on transportation systems fuelled by oil. What is required is a mobility system capable of delivering the required capacity and performance while based on zero-carbon energy resources. Transport is a key component of the low-carbon future envisaged by the Paris Climate Agreement. In New Zealand buildings are serviced largely by renewable electricity, whereas road transport produces more than 40% of total CO_2 emissions. The EU says that emissions need to fall by 80% by 2050 to meet the Paris target. If transport is to play a part in this, it means that transport emissions must also be reduced by at least 80% by 2050. Many transport ideas seem to focus on new technologies such as electric vehicles or self-driving cars, but transport is also a result of built environment choices and behaviour changes. How much difference could these apparently "non-transport" options make in developing workable transport for a low-carbon city?

Keywords: Low-carbon, transport behaviour, choices

Introduction

The Lonely Planet travel guide described Wellington, New Zealand as "the coolest little capital in the world" (New Zealand Herald, 2010). This paper describes the initial findings of research at Victoria University of Wellington into how transport in Wellington could change, in the light of the Paris Climate Agreement, to make it "the coolest little low-carbon capital". If possible for one city, these changes could be possible in many cities as the world seeks ways to move towards a more sustainable path. There is little point in having a city made up of sustainable buildings if they are not connected by sustainable transport. At a local level, Wellington City Council has proposed a transformation of the city to a "Low Carbon Capital" (WCC, 2016) and a key part of this transformation will need to come from the transport sector as this is such a large component of total emissions. Many transport ideas seem to focus on new technologies such as electric vehicles or self-driving cars, but transport is also a result of people's choices and behaviour. How much difference could these make in developing a low-carbon city?

Transport and emissions?

Transportation is a basic need and the history of transportation is as old as humanity. From the simple movement of humans emerged the demand for different modes of transportation not only for people but also for their goods. Increases in economic growth have enhanced the purchasing power of individuals and hence have led to increasing private vehicle ownership especially in urban areas (WEC, 2011, 12-14). Thus, it is estimated that private vehicle usage will be doubled by the year 2040 (ExxonMobil, 2013, 17).

No one can deny that economic prosperity is reliant on human mobility and freight transportation but the adverse effects of mobility services need serious attention, particularly in the light of the climate agreement concluded in Paris. The CoP21, United Nations Framework Convention on Climate Change (UNFCC), 21st session of the Conference of Parties was held in December 2015 in Paris, France. After lengthy deliberations, 196 countries (New Zealand is one of the signatories) successfully negotiated the Paris Climate Agreement with the global goal of holding temperature increase to below 2^0 C above pre-industrial levels, with parties agreeing to make efforts to keep it below 1.5^0 C (Climate Action, 2015). The situation is urgent, by 2015 the UK Meteorological Office reported that global average temperature would that year for the first time be already 1 degree Celsius above the pre-industrial figure (Met Office, 2015).

Transport without emissions?

The industrial revolution, which brought with it significant changes in modes of transport, first by water, then rail and finally the private car, has been powered by fossil fuels and as a result concentrations of CO_2 in the atmosphere have risen, forming a blanket around the planet, trapping heat reflected from the earth's surface. Mobility is an important part of living standards; it underpins a country's economy and is a substantial contributor to its GDP. On the other hand it will be difficult to achieve reduced CO_2 emissions in cities which rely on the continued use of transportation systems largely based on private vehicles fuelled by oil.

What is required is a system of mobility capable of delivering the required capacity and performance while based on zero-carbon energy resources and at the same time compatible with the desired lifestyle as well as being clean and affordable. Transport is a key component of the low-carbon future envisaged by the Paris Agreement. This is particularly true in New Zealand where dwellings are serviced largely by electricity sourced to a considerable extent from renewable hydroelectricity, whereas transport relies on oil. Indeed, road transport, fuelled by oil, provides the largest share of New Zealand's CO_2 emissions, more than 40 % of the total (MfE, 2013, 55). New Zealand's aim is to reduce its climate-related emissions to 50% below 1990 levels by 2050 (MfE, 2013, 62) but the European Union says that emissions need to fall by 80 - 95% by 2050 compared to 1990 levels to meet the Paris target (EC, 2016). If transport is to play a part in this, it means that transport emissions must also be reduced by at least 80% by 2050.

Can we do it with technology?

To provide a transport system for Wellington that meets the Paris Agreement's requirement to reduce carbon dioxide emissions by 80% will require reducing the emissions from transportation by the same amount. Could this be done? The average fuel consumption of the light vehicle fleet in 2000 was 9.75 litres/100 km (MoT, 2016, 4). An 80% reduction would mean cars with an average fuel consumption of under 2 litres of fuel per 100km. This seems unlikely to be achieved by 2050. Because of the slowness of the replacement of the New Zealand vehicle fleet, with the average age of vehicles now over 14 years (MoT, 2016, 4) it is not likely that new low-carbon technology, such as electric vehicles, will have sufficient time to replace existing vehicles before 2050. In addition, recent research shows that a change in New Zealand to an all-electric fleet of private cars would reduce emissions by only 60% (EECA, 2015, Table 15, 72) which is not enough. Other new technologies, such as driverless cars, will make transport easier so are unlikely to reduce travel distances and cannot be assumed to offer emissions reductions, since their focus is on control rather than fuel consumption. New technologies are also expensive currently compared to existing vehicles, making their likely uptake slow. The best that could be assumed is a halving of the average fuel efficiency of the existing fleet, to 4.9 litres per 100km by 2050. Petrol fuelled cars with this level of fuel consumption are already widely available, the eight year old Toyota Prius driven by one of the authors has a recorded lifetime average consumption of 4.6 litres per 100km.

Can we do it with behaviour?

Having halved vehicle emissions through the technology of reduced fuel consumption, the next strategy to achieve the target of 80% mitigation of emissions could be by halving the annual private vehicle travel. The present annual light vehicle travel in New Zealand is just over 11,000 km (MoT, 2016, 3) which could be reduced to say 6,000 km, although this would have to be achieved in line with an increase in regional population to nearly 650,000 by 2050 which will increase annual vehicle kilometres travelled (VKT), and in line with increased economic growth which could also increase VKT.

A Sustainable Perspective for Wellington (SuPerW) Approach to reduce travel distance

The different components of a future low-carbon transport system are discussed below under the heading of a Sustainable Perspective for Wellington (SuPerW) approach. The possible travel reduction assumed to be provided by each category is given after the discussion of that category.

SuPerW Built environment

A smart built environment has a crucial effect, albeit to varying degrees, on travel trends, with higher densities, a decent mix of uses and walkable neighbourhoods contributing to lower vehicle travel and fuel consumption. But at the same time public opinion is divided over preferences for green growth versus sprawl growth. Gross neighbourhood densities in the range of 1500 – 4000 persons per square km (ppsk) are found to act as the threshold for the most meaningful reductions in automobile travel (USDE, 2013). A recent study found that new patterns of built environment based on compact, walkable, easily accessible transit facilities could reduce GHG emissions from transportation sources up to 10% by 2050 which is equivalent to decrease in VKT by 15 % to 20% (USDE, 2013: 13). The land use impacts involved changes in neighbourhoods where ultimately vehicular travel is reduced by 20% to 40%. The *Moving Cooler* study (Urban Land Institute, 2009) found that VKT can be reduced by 2% to 13% based on built environment changes with gross densities of at least 1500 ppsk. Once suitable density exists, it generates destinations close to walk to, and reasonably competitive transit alternatives from a travel time and cost standpoint.

In the SuPerW strategy changes in the existing Wellington built environment are assumed to provide the conditions to promote reductions in VKT as set out below, by making easier the choice of modes of transport other than private cars.

Mode 1: Walking;
The cheapest, healthiest, environmentally friendly and space efficient way to travel is walking. Normally a person walking covers 1312 steps in 1km (Kyle's Converter, 2017). In NZ the amount of walking done per person per week varies by main urban centre or rural area (MoT, 2015). According to the USA Centres for Disease Control and Prevention "For the first time in history, the current generation of youth will live shorter lives than their parents" because of lack of exercise (Gotschi and Mills, 2008, 29). In recent decades we have consistently increased our calorie intake while decreasing our activity level. Especially in the last two decades the results of the obesity epidemic became apparent in sharply increased obesity rates (Flegal et al., 2002; Kuczmarski et al., 1994). A surprising 30% of private car trips in New Zealand are for less than 2 km (NZTA, 2016), a distance that could be walked, with additional economic, health and social benefits for society (LTSA, 2000). New Zealanders are undertaking fewer journeys per capita where walking is the sole mode of transport, there were 400,000 fewer walk-only trips in 1997/98 than in 1989/90. The number of walk-only trips rose slightly between 2005 and 2012 but the overall trend during the last decade shows a decreasing trend of 0.3% per year against population growth of 0.9% during the same period. The development of a dedicated walkway network for a community of 50,000 people would cost less than one km of motorway (NZTA, 2016). An increase in cycling could also be encouraged. Both these non-motorized modes of transport would be made considerably safer by the resulting reduction in car use. It is recommended for health that people walk 10,000 steps a day, a distance of 8 km (NHS Choices, 2014). If we all simply walked as recommended, this alone would be nearly 3000 km a year.

In the SuPerW strategy walking is assumed to be 1,500 km per year, half the 10,000 steps per day target.

Mode 2: Cycling;
The fastest (for shorter distances), good exercise and least expensive way to travel by vehicle is cycling. This mode of travel is good for local businesses as cyclists are often more likely to shop locally (City of Vancouver, 2011, 27). A fast growing development for encouraging cycling is electric bicycles. Electric bicycles offer multi-dimensional advantages of easy handling, cheaper and environmentally friendly transport for longer distance travel with easily overcome inclines and wind pressure and provision of load carrying capacity. These make this option an alternative to private cars for shorter trips as well as sensible choice for recreational activities (Wachotsch et al, 2014). The CDC recommendation for physical activity is 30 minutes of moderate exercise on most days (Gotschi and Mills, 2008, 29), equivalent to 8 Km of bicycling. By bringing this easy and simple change in transport behaviour it would be possible potentially to shift about 50% of car traffic load given that currently almost half of car travel trips are under 6 km long. (NZTA, 2011). The hilly terrain of the Wellington region might be a hurdle to shift this entire 50 % share to cycling, even with electric assistance. Annual car travel (as driver and passenger) in Wellington is just over 11,000 km per person (MoT, 2016, 3). Half of this distance is trips of less than 6 km that would be suitable for cycling, so it is assumed that around a third of these trips could be taken by cycling.

In the SuPerW strategy it is assumed that electric and pedal cycling may contribute around 2,000 km of cycle travel by 2050.

Mode 3: Public transport;

Wellington Region public transport has increased in the distance travelled per year from 345 million km in 1999/2000 to 430 million km in 2015/2016, an increase of 25% in 15 years. Over the same period, Wellington's bus and rail emissions have not increased (URS, 2014, Fig 5.59, 76). In spite of rising population, annual distance travelled per person on Wellington's public transport has also risen and is now around 1070km, compared with around 770 km in 2001 (calculated from data from Metlink, 2016 and Statistics New Zealand). If this rate of increase is increased through active promotion of public transport, it could result in a significant increase in public transport use in 30 years' time, meaning that at least 2,500 km of annual travel will be by public transport by 2050. This would comprise less than 25% of travel, in comparison, Vancouver intends 35% of travel to be by public transport by 2040 (City of Vancouver, 2011, 10). Subsidised public transport fares, free bus passes from employers, a well-connected efficient network, a new more comfortable bus fleet and other improvements will be needed to motivate the public to divert from private cars to public transport by 2050.

In the SuPerW strategy it is assumed that public transport will comprise 2,500 km of annual travel per person.

Mode changes: Summary

The suggested transport mode changes outlined above are in line with current trends and reflect realistic targets. The figures allocated to the different modes could change relative to one another but it appears that together non-car modes could amount to 6,000 km per person per year of travel, which is nearly 50% of total current annual travel in Wellington (12,231 km) (MoT, 2015b). This still leaves about 6,250 km of travel that is currently done in cars. The non-car modes are not necessarily zero-emission and strategies for moving public transport, in particular buses, from diesel to electric propulsion would be an essential part of a strategy for change. In Wellington, there is scope for introduction and implementation of policies similar to the TravelSmart programme that was used in Australia (DEH, 2005). This utilized a number of behaviour change techniques to reduce car use for household, commuting and school trips. It was found that a community based social marketing approach to persuade people onto other modes combined with measures to disincentivize car use (removing downtown parking) could change travel behaviour by reducing car use up to 60%. By shifting public to public transport up to 50% make possible CO_2 reductions ranging from 0.12-0.39 ton/capita/year.

The results

Table 1 presents the results of the application of the SuPerW Strategy to three possible scenarios for Wellington's passenger transport in 2050. In Table 1 the private car fleet is expected to rise from 277,000 in 2014 to 440,000 in 2050 as a result of population growth. Three scenarios are shown for assumptions about the amount of private car use in 2050, these are "Ideal", "Moderate" and "Business as Usual". The first assumes a modest reduction in car use, the second is as now and the third assumes greater distance travelled in 2050, but all are based on an increase in the size of the car fleet as well an increase in non-car modes as proposed in the SuPerW Strategy.

Table 1: 2014 passenger transport in Wellington and three scenarios for 2050

Wellington region	**2014**				**2050**					
	Fleet (1000)	Share in dist-ance	CO_2 emissions tonnes	Km pp/y	Fleet (1000)	Share in dist-ance	CO_2 emiss-ions tonnes	Km pp/y (per person per year)		
								Ideal	Mod-erate	Busi-ness as usual
Car	277	58%	703,000 65% of land transport*	7064	440	35%	142,562 65% of CO_2 target *	2,000	3,500	5,200
Car Passenger		31%		3736		22%		1,000	2,500	3,800
Pedestrian		2%		251		12%		1,500	1,500	1,500
Cyclist		1%		124		15%		2,000	2,000	2,000
Pub. Tran	0.75	8%	6,964 0.6% of land transport	1021	1.4	16%	2,200 1% of CO_2 target	2,500	2,500	2,500
CO_2 & fuel economy								108g/ km 4.3l/ 100k	54g/ km 2.3l/ 100k	36g/ km 1.6l/ 100k
Total			1,096,636	12,231			**220,820 CO_2 target**	9,000	12,000	15,000

* The remainder of the land transport emissions comprise 15% contribution from light commercial vehicles and 19.5% contribution from heavy commercial vehicles. These percentages are assumed to remain the same in the 2050 scenario.

Based on the required reduction in CO_2 emissions the car fleet can have total emissions of 142,562 tonnes per year. If annual travel distance reduces from over 12,000km per year to 9,000 (the "Ideal" scenario) the emissions for each car need to be 108kg CO_2/km. This equates to a fuel consumption of around 4.3 litres/100km. To put this into perspective, a UK based car review website states that there are already 524 models of cars on the market with CO2 emissions that fall into the range of 0 - 100g/km (CarPages, 2017). The emissions of light vehicles entering the New Zealand fleet have improved from about 220g CO_2/km in 2005 to 181g CO_2/km in 2015 (MoT, 2016, 56). Given this rate of reduction of 40 grams in ten years it is likely that the average emission of new vehicles could be 140g by 2030 and 100g by 2040, giving an overall fleet average of 100g by 2050.

It is important to note from Table 1 that both the "Moderate" and "Business as usual" scenarios would need much more radical changes in car technology to achieve the necessary emissions reductions. The "Ideal" scenario offers the lowest likely cost and is the simplest way to meet the Paris target.

Figure 1 shows the projected travel mode distance km per person per year in ideal scenario to be achieved in 2050.

Fig 1. Wellington Travel- travel mode distance in ideal scenario for 2050.

Conclusion

Overall the focus of this research is to accommodate the increased demand for travel due to the Wellington region's prosperity and population growth, to provide 80% reduction in transport generated greenhouse gas emissions and at the same time safe, affordable and easy access to home and work and amenities. This will require the implementation of policies, at local and national level, to change motivation towards using public transport, walking and cycling. Planning policies will need to encourage a built environment which actively promotes non-car travel. In addition there is a need to make all three non-car modes more attractive, reliable, and comfortable plus the promotion of more fuel-efficient cars. The aim is to bring about a behavioural change for a shift to public transport, walking and cycling and a reduction of 50% in private vehicle use. This could be a cost-effective way to meet the Paris target of an 80% reduction in emissions without the need for promoting expensive new technologies.

There is an answer for providing the kind of transport that Wellington needs to play its part in meeting the goals of the Paris Climate Agreement. It is not based on any radical change or futuristic technology, but can be achieved though using a combination of simple, available and affordable technology and simple changes in behaviour. We don't need to change our cars, we just need to change our minds.

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Ventilation

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Skycourt as a ventilated buffer zone in office buildings: assessing energy performance and thermal comfort

Saba Alnusairat[1], Phil Jones[1] and Shan Shan Hou[1]

[1] Welsh School of Architecture, Cardiff University, UK, alnusairatsf@cardiff.ac.uk

Abstract: Skycourts, recently, have been considered as beneficial spaces in commercial buildings, in particular offices. Skycourts are perceived as spaces that act as transitional and recreational nodes. Research considering the performance in response to conditions in these regions is steadily growing. However, there is a lack of conclusive results in the available literature about the actual energy performance of these spaces. The primary purpose of this paper is to examine the potential of the skycourt to perform as a buffer zone that suits to the ventilation strategy in office buildings in a temperate climate, thus could potentially reduce energy demands for heating and cooling, furthermore ensure thermal comfort in these spaces. Using a hypothetical reference office building in London, coupled Building Energy Simulation (BES) and Computational Fluid Dynamics (CFD) are carried out for two ventilation modes; mode one, the base model represents skycourt with isolated mechanical ventilation and mode two, alternative models that incorporate combined ventilation strategies with the adjacent offices' zones of the skycourt. These are simulated and evaluated regarding energy consumption and thermal comfort. Overall, the simulation results highlight that the incorporation of skycourt as buffer zone can potentially have a significant impact on the annual energy consumption.

Keywords: Skycourt, Buffer zone, Coupling simulation, Office buildings

Introduction

Skycourt is acknowledged nowadays as a beneficial space in buildings. This integrated area offers a modern alternative to the vernacular courtyard or atrium thus could support the social, environmental and economic functions in offices. For example, it can operate as common public space for social interaction, relaxation and leisure in areas, where there is usually lack of engagement between occupants. As well as, it might function as a transitional space to facilitate ease movement and clearness of wayfinding. Skycourt perhaps provides segmentation barriers between spaces. In addition, it can be integrated into the architectural design to benefit from the natural energy sources such as sun and wind to allow views and daylighting, and facilitate ventilation. Thus, it could provide significant outcomes of conserving energy and improving the health and wellbeing of occupants. Moreover, a skycourt could perform as buffer zone between the indoor and the outdoor consequently could mediate the climate conditions, provide thermal and acoustic protection to the interior, reduce heat loss and avoid unwanted solar gain. A growing body of literature has studied the influence of various integrated elements on the performance of buildings, such as skycourts (Ghazali et al, 2014; Pomeroy, 2014; Taib et al, 2010; Etheridge and Ford, 2008; Yeang, 1999). However, the weakness of current studies is the limitations in addressing the impact of such elements by its own on the total performance of the building.

This paper presents an independent study for the office's buildings in temperate regions, represented by London City underlines the function of skycourt as a buffer zone that located between the external façade and indoor controlled office zones, which are subject to mechanical ventilation. Heating and cooling processes consume approximately third of energy use in office buildings (Wood and Salib, 2013). Therefore, minimising energy demand by developing efficient strategies for ventilation, heating and cooling is crucial. This paper focuses on the potentials of skycourt to accomplish energy efficient solution stressing reduction of heating and cooling loads besides ensures thermal comfort in these spaces. It suggests several ventilation strategies relies on the fresh air required for the adjacent office's zones. The air movement causes convective heat transfer inside the skycourt under the buoyancy difference due to variation in temperature and height between the regions of the skycourt. This mechanism could induce thermal comfort significantly cooling without the need for consuming heating neither cooling loads for skycourt.

Methodology

Coupled Building Energy Simulation (BES) and Computational Fluid Dynamic (CFD)

Numerical simulations including Building Energy Simulation (BES) and Computational Fluid Dynamics (CFD) can provide a useful and quick prediction for the thermal conditions and energy performance of buildings. However, there are limitations in using these methods separately. Coupling BES and CFD simulation have generated considerable recent research interest. In this technique, two interrelated models are integrated to produce complementary detailed information by exchanging boundary conditions data. See Figure 1.

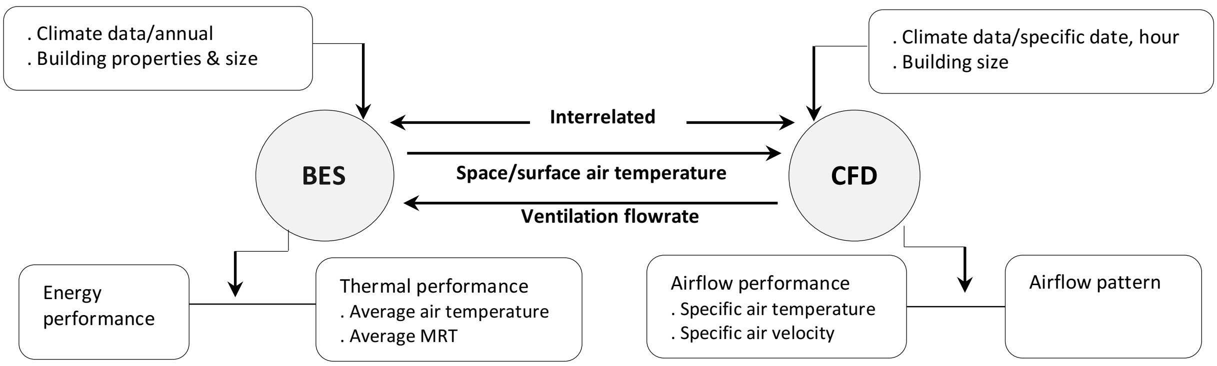

Figure 1. Diagram shows the BES and CFD coupling models

Coupling simulation is highly recommended in ventilation studies due to its accuracy and efficiency. This method could improve prediction of cooling and heating load at least 10% (Zhai et al, 2002). Furthermore, it might eliminate simulation time cost and requirements; it is found that full CFD requires about 12 hours with parallel workstation while coupling CFD requires less than one hour with 1 Gbytes computer to evaluate the same indoor environment (Wang and Wong, 2009). Integration between BES and CFD has been optimised with other numerical methods, theoretical analysis and experimental work. That is exemplified in the works undertaken by Barbason and Reiter (2014); Cropper et al (2010); Wang and Wong (2008); Zhai and Chen (2005); Zhai and Yan (2003); Bartak et al (2002). The validation showed that iteration between BES and CFD could produce correct and converged solutions and inform accurate and efficient prediction for thermal and airflow pattern in short time. Consequently, coupling could be considered as an advanced simulation tool to test the environment of different buildings.

The study aims to investigate the influence of several ventilation strategies in the skycourt space and compare the results regarding thermal comfort at the occupancy level and the energy consumption for heating and cooling. Therefore, coupling model is carried out to predict the performance. The building energy model, HTB2 and the airflow model, WinAir were integrated into the study. The ''Heat Transfer through Building'' (HTB2) was developed by the Welsh School of Architecture (WSA), Cardiff University. This numerical model can predict the indoor thermal performance and estimate the energy demands for buildings (Lewis and Alexander, 1990). HTB2 is recommended due to its high validity since it has been developed over thirty years. Furthermore, it has undergone a series of extensive testing including the IEA BESTEST (Neymark et al, 2011), IEA Task 12 (Lomas et al, 1994) and IEA Annex 1 (Oscar Faber and Partners, 1980) and. Also, it has been validated under ASHRAE standards and used to develop benchmarks for other standards (Alexander and Jenkins, 2015). Coupling HTB2 with WinAir as a CFD can accomplish graduating and accurate information of air temperature, air velocity and air concentration showing the airflow pattern in the skycourt. External coupling is adopted in this study; two models were built separately, a schematic model in the HTB2 and a grid model in the WinAir. The static strategy is carried out to bridge the two models; the thermal conditions for the CFD model are obtained from previously calculated values from the HTB2. These include the surfaces heat transfer, the inlet air supply, the outlet air exhaust and the internal heat gains involved inside the skycourt.

Coupling Simulation

The model is simplified to an eight-storey office building located in temperate climate represented by London. This building combines six-storey skycourt, the hollowed-out pattern. See Figure 2.

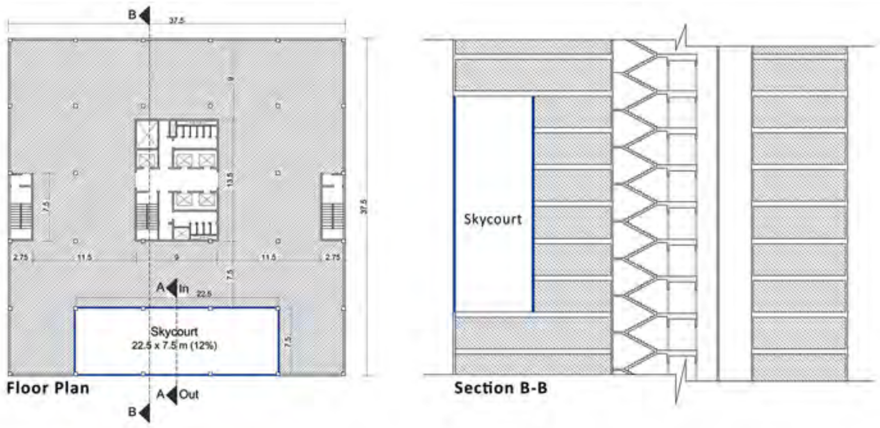

Figure 2. The spatial configurations of skycourt (the white shaded zone) considered in the study

Modelling framework

The simulation is carried out all over the year under different seasons: summer, winter and mid seasons using the HTB2. However, the CFD is measured considering the climate data for the peak summer hour, the coldest winter hour and the mid-temperature hour. These combine the following parameters: the hottest external temperature is 28.3°C on June 28th at 14.00, while the coldest external temperature is -5.0°C on December 7th at 9.00 am. The mid-temperature is 13.2°C on April 19 at 9.00 am. The adapted settings and conditions of the simulation process are defined in Table 1. Similar conditions are conducted for the six models except for the ventilation mode. However, the minimum ventilation rate to maintain an accepted air-quality is defined based on the number of occupants and taking into consideration the building envelope airtightness (infiltration). In the simulation, the heating set point is 18°C, and the cooling set point is 25°C. Single set point controls are used for cooling in the offices, while heating is controlled by air handling unit.

Table 1. Simulation settings for office spaces

Internal heat gain*		**Building Fabric**		**Ventilation setting**	
Workplace density	12 m^2 /person	Glazing U-value	1.5 (W/m^2.C)	Infiltration rate	3.5 $m^3/(m^2$.hr) at 50Pa
		g-value	0.4		
People	12 w/m^2	Window to wall ratio	70%	Air supply rate	10 L/s per person
Equipment	15 w/m^2	External wall U-value	0.18 (W/m^2.C)	Heating set-point	18°C
Lighting	12 w/m^2	Internal wall U-value	0.22 (W/m^2.C)	Cooling set- point	25°C
		Floor/ceiling U-value	0.20 (W/m^2.C)	Operating time	08:00-18:00

*Occupancy profile: the building occupied five days a week, based on the following schedule, for offices 09:00-13:00 occupied 100%, 13:00-14:00 occupied 70%, 14:00-18:00 occupied 100%. For Skycourt 09:00-18:00 occupied 100%

The ventilation strategies

The study was carried out in two ventilation manners,

1. The base case, this represents the current practice, which considers isolated mechanical heating, cooling and ventilation for the skycourt. The base model is used as a benchmark reference to compare the energy and thermal performance when other ventilation strategies are applied. See Figure 3

Skycourt is ventilated isolatable

Base Case (BC)

skycourt and adjacent offices are mechanically ventilated, heated and cooled separately

. Air change rate for offices is 3.1 ac/h at 18° C
. Air change rate for skycourt is 0.167 ac/h at 18°C

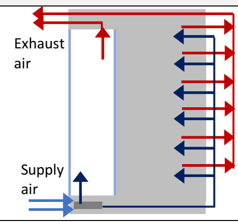

Figure 3. Proposed ventilation strategy for the base case - mode one

2. Skycourt as a buffer area that does not consume energy for heating either cooling. Five ventilation strategies are suggested to mediate the internal environment of the skycourt depending on the required fresh air for the adjacent offices as air supply or air exhaust. These combined strategies are categorised into three principles. First, skycourt is a sealed space. Second, the exhaust air from the offices mediates the skycourt. Finally, skycourt is ventilated by the supply fresh air required for the offices. Simulation is carried out to nominate the optimum approach. Figure 4 illustrates the principles, air movement and simulation settings for the proposed strategies.

Results and Discussion

The energy demand for heating and cooling of the building and the thermal comfort conditions at the occupancy level of the skycourt are taken as criteria of comparison. Thus to define the optimum ventilation strategy.

Energy performance comparison

The results obtained from the BES of the monthly heating, cooling, solar, fabric, ventilation and power loads for the skycourt are shown in Figure 5 . It is apparent from the charts that the power and solar gain are the same due to similar simulation settings.

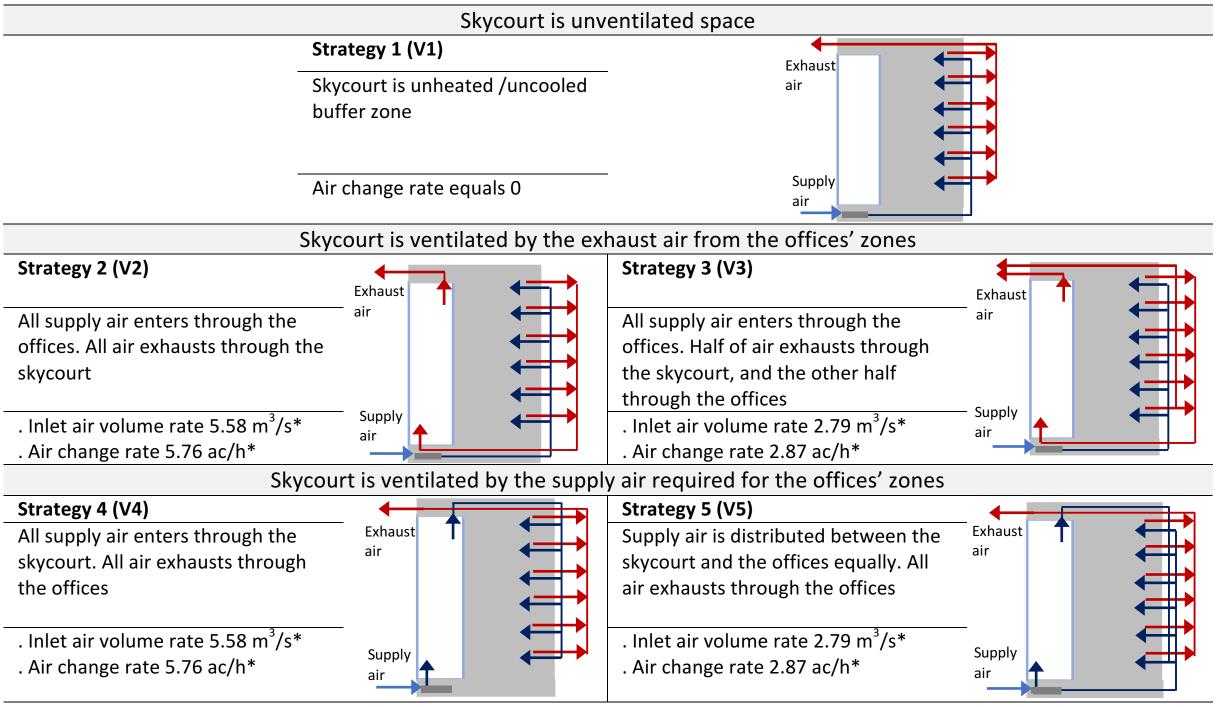

Figure 4. Proposed ventilation strategies for the skycourt for mode two

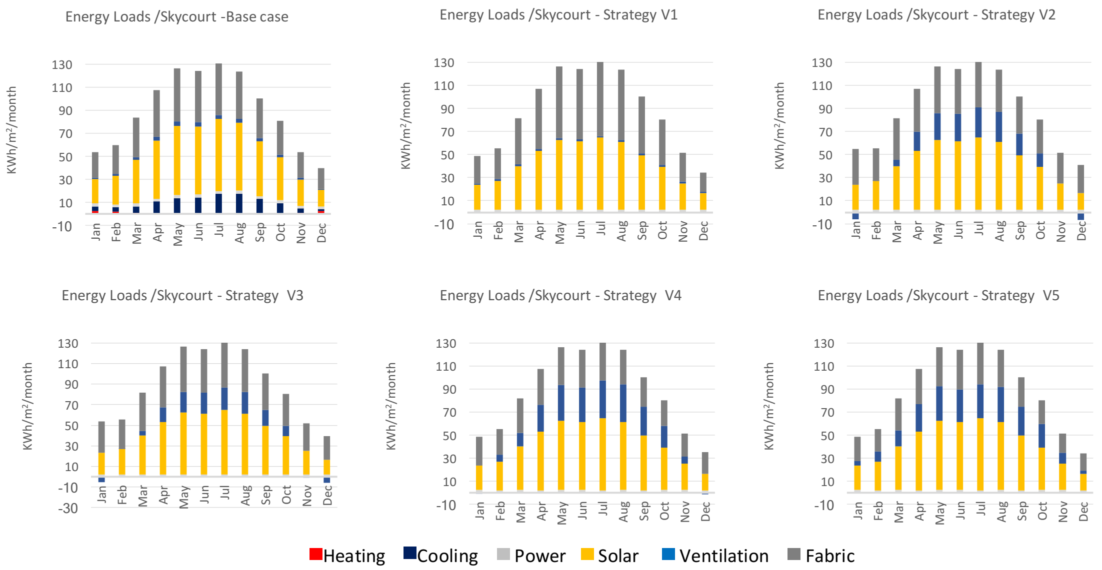

Figure 5. Results of the monthly heating, cooling, solar, fabric, ventilation and power loads for skycourt

In addition, it is seen that strategy two, three, four and five account high ventilation load due to the airflow mechanism. However, as ventilation load increases, fabric load decreases. Strategy one records the least ventilation loss by 17.94KWh/m^2/year and the highest fabric loss by 522.63 KWh/m^2/year. Strategy two and three account less ventilation load (138.83KWh/m^2/year and 117.0 KWh/m^2/year) correlated to strategy four and five (216.37 KWh/m^2/year and 227.03 KWh/m^2/year). That is due to the temperature difference of the inlet air to the skycourt. It is higher in the previous two cases. The results, as shown in Figure 6, indicate that the proposed ventilation strategies account almost 50% reduction in the total annual energy demand for heating and cooling in comparison to the base case. In strategy two, the demand is reduced from 220KWh/m^2/year to 91.9 KWh/m^2/year for each floor. Strategy four and five report higher demand than strategy one, two and three. From this figure, it is clear that less inlet airflow rate requires more heating and cooling demand. The strategies account sequentially the following demand 94.33, 91.9, 93.21, 110.05, 98.30 KWh/m^2/year.

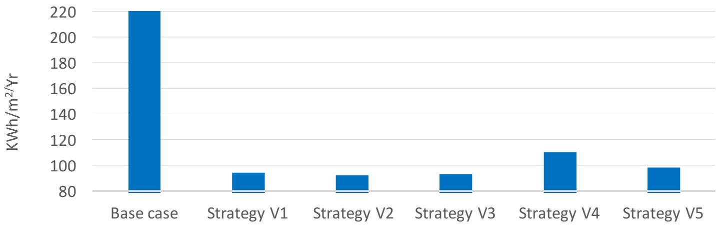

Figure 6. Results of the annual heating and cooling demand

Thermal performance of skycourt comparison

The CFD results predicting the thermal conditions -air temperature gradient (°C) and air speed (m/s) in the skycourt in several seasons are demonstrated in Figure 7. Cross-section location (A-A) is shown in Figure 2. The comfort criteria recommended by the British Council for Offices (BCO) guide (2014) is adapted to verify the thermal conditions at the occupancy level of the skycourt (air temperature ranges in summer 24°C ± 2°C, in winter 20°C ± 2°C and airspeed ranges between 0.1m/s and 0.2m/s). It is evident that the skycourt cannot be considered a thermal comfort space without inlet airflow. The indoor air temperature in summer for strategy one is very high and reaches 50°C at the hottest hour, on the other hand, it is extremely cold in winter with average 8°C at the coldest hour. In additions, the results show that the skycourt is thermally comfortable in transitional seasons. However, the indoor air quality is not satisfied.

The air temperature in the skycourt at summer when adopting strategy two ranges between 25.0°C and 32.0°C in the whole skycourt space, and about 26.0°C of 0.2m/s average air speed at the occupancy level. At the coldest hour, the temperature graduated from 14.2°C to 19.9°C with 0.3m/s. This range might not provide the required comfort degree in winter. However, it is the best temperature recorded between the proposed ventilation strategies in winter. On the other hand, reducing the airflow volume rate inside the skycourt as suggested in strategy three causes raise the air temperature in summer and decline in winter. At peak hour, the temperature increases from 25.0°C to 29.0°C of 0.14m/s, whereas at a cold hour from 12.8°C to 19.7°C of 0.36m/s airspeed. Considering the skycourt as a space for mediating the air temperature before entering the offices' zones as suggested in strategy four, accounts the most comfort conditions in summer peak time. Air temperature ranges between 23.3°C and 26.5°C and air speed records 0.22m/s. Whereas, when the external air temperature is -5.1°C, the temperature inside the skycourt ranges from 13.4°C to 17.9°C with 0.28m/s. Strategy five accounts 27.6°C to 31.5°C with 0.14m/s at summer peak hour and 11.9°C to 17.7°C with 0.32m/s at the coldest hour. The simulation at a normal hour in spring accounts the following results for the skycourt at the occupancy level; 22.7°C, 0.06m/s for strategy one, 22.1°C, 0.17m/s for strategy two, 22.0°C, 0.1m/s for strategy three, 19.0°C, 0.18m/s for strategy four and finally 18.8°C, 0.12m/s for strategy five.

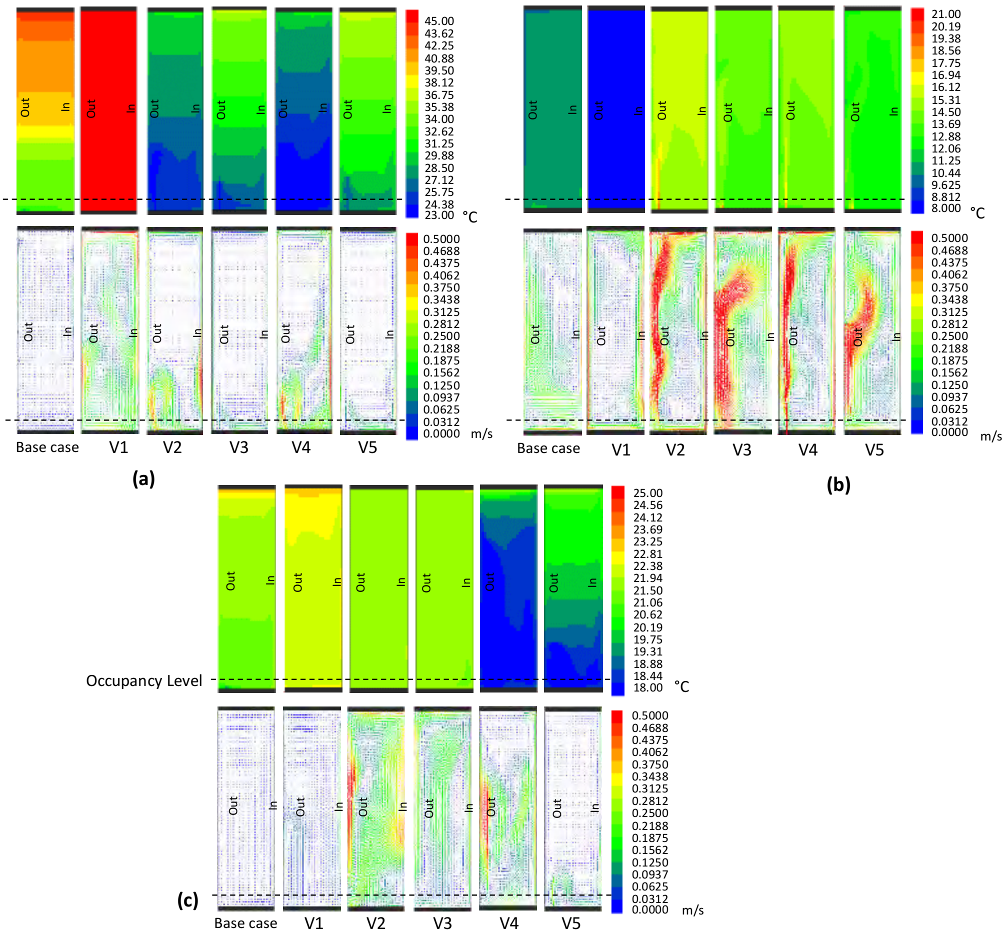

Figure 7. Results of the thermal conditions in skycourt at (a) the hottest hour in summer, (b) the coldest hour in winter and (c) the typical hour in mid-season

Discussion

The simulation results indicate that integration of skycourt in an office building as a space adopts isolated mechanical ventilation increases extremely the total energy demand significantly the cooling loads. In this case, air temperature seems to be comfortable at the occupant level of the skycourt. However, the supply air rate is considered low and might not be efficient due to the height of the skycourt. However, the simulation results highlight that the combined ventilation strategies for the skycourt show potential for energy saving and thermal comfort nevertheless differently. The findings of the study show that the optimum ventilation strategy to minimise the requirements of energy besides ensuring the thermal comfort at the skycourt is strategy two.

Conclusion

The paper has discussed the thermal and energy performance of a skycourt when incorporated as a buffer zone in an office building. Several ventilation strategies based on the concept that skycourt is a non-cooled and unheated space -does not consume energy for cooling either heating- are investigated to mediate the internal thermal conditions of the skycourt. These ventilation systems were developed depending on the required fresh air for the adjacent offices of the skycourt as air supply or air exhaust. The results indicate that a combined ventilation strategy for the skycourt enhances the energy saving for the building and provides advantages on occupants' thermal comfort. A ventilation strategy that depends on the maximum airflow volume rate exhausted from the adjacent offices to the skycourt has a significant effect on cooling the skycourt space. In addition, it can achieve about 58% heating and cooling energy saving compared with mechanical heating and cooling. Furthermore, this strategy could affect the nearby offices positively in terms of reducing heating and cooling demand and providing shading. In addition, the study found that coupling models (HTB2 and CFD-WinAir) provides an efficient prediction of the indoor environment for the skycourt.

Acknowledgement

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Indoor comfort evaluation by natural ventilation in hot climates: Heat Balance Index

José Antonio Castillo[1] and Guadalupe Huelsz[2]

[1] Centro de Investigaciones en Arquitectura, Urbanismo y Paisaje, Facultad de Arquitectura, Universidad Nacional Autónoma de México, Ciudad Universitaria, Av. Universidad 3000, Coyoacán, 04510, Ciudad de México, México. Email: jacat@ier.unam.mx
[2] Instituto de Energías Renovables, Universidad Nacional Autónoma de México, A.P. 34 Temixco Centro, 62580, Temixco, Mor., México. Email: ghl@ier.unam.mx

Abstract: Natural ventilation is a passive alternative to create comfort and healthy indoor conditions. Particularly in hot humid climates, full day ventilation is the best strategy to promote thermal comfort conditions, because the increase of the airflow velocity increases the sweat evaporative cooling of the occupants. Thus, it is important to assess the indoor natural ventilation in terms of the thermal comfort. This work uses a novel method, the Heat Balance Index (HBI) to evaluate the thermal comfort of the occupants in terms of the indoor natural ventilation in hot climates. HBI gives a method to define the comfort velocity range useful to calculate the well-ventilated percentage of a space. HBI considers the metabolic heat production and the heat transfer between the body and the surrounding given by the mechanisms of radiation, convection and evaporation. The HBI is applied to a study case based on Computational Fluid Dynamics simulations of a room with a window and a windexchanger in one climate condition of a Mexican city. The study case simulations are validated with experiment results. The application example gives the percentages of the living volume with discomfort by low ventilation, with comfort by adequate ventilation and discomfort by high ventilation.

Keywords: Natural ventilation, hygrothermal comfort evaluation, CFD simulations, heat balance, hot-humid climate

Introduction

Natural ventilation is an alternative to provide comfort and healthy indoor conditions, reducing the energy consumption. Typically, the energy cost of a naturally ventilated building is 40% less than that of an air-conditioned building (EEBPP, 1993). For hot humid climates, full day ventilation is the better strategy to promote thermal comfort conditions (Liping and Hien, 2007), because the increase of the airflow velocity increases the sweat evaporative cooling of the occupants.

For ventilation performance evaluation, the most used parameters are the mean magnitude velocity at the space, U, and the concept of well-ventilated percentage of a space, P, that is defined by Bastide et al. (2006) as the percentage of the volume with velocities within a velocity range (U_{min}; U_{max}). They show that the results are very sensitive to the choice of U_{min} and U_{max}, but they do not give a methodology to select these values.

For the evaluation of thermal comfort, the most common method is the Predicted Mean Vote, PMV, with the Predicted Percentage Dissatisfied, PPD, (Fanger, 1970). This method has been developed in controlled conditions, not in natural ventilated buildings.

However, the temperature ranges of validity of the models used by all these indices do not cover the high temperatures of hot climates. There are thermal comfort models useful for non air-conditioned spaces, i.e. naturally ventilated spaces, such as adaptative comfort temperature models that are functions of the monthly mean of the outdoor air temperature (De Dear and Brager, 2002; Humphreys and Nicol, 2000; Yang, 2003). Only one study was found that proposes a method for the evaluation of natural ventilation in terms of thermal comfort (Su et al., 2009). The authors propose temperature neutrality formulas, one for indoor air temperature over 28 °C and other for indoor air temperature below 28 °C, that are functions of the monthly mean of outdoor air temperature, the relative humidity and the airflow velocity near occupants. They considered a comfort zone band width of 4 °C. Unfortunately, the authors do not give details of the methodology followed to derive these formulas.

The Heat Stress Index, HSI, is a method used to evaluate thermal comfort for indoor in hot conditions (Belding and Hatch, 1955). It is defined as the ratio of the required evaporation to the maximum evaporative capacity of the air. The Index of Thermal Stress is a method to evaluate thermal comfort for outdoors in hot climates, ITS (Givoni 1969). Also for outdoors, but for cold climates, is the windchill correction (Aynsley, 1974).

The Heat Balance Index, HBI, (Castillo and Huelsz, 2017) provides a method to define the comfort velocity range (U_{min}; U_{max}) in hot climates. The HBI is useful to calculate the well-ventilated percentage of a space. In the next section, more details of HBI are given. This paper presents an application example of the HBI to evaluate the indoor natural ventilation in hot climates in terms of the thermal comfort of the occupants. The application example is applied in a room with a window and one windexchanger by using Computational Fluid Dynamics (CFD) simulations with one weather condition of a Mexican city.

Heat Balance Index

The thermal comfort is obtained when the metabolic heat production is totally transferred to the surroundings without heat stress, the Heat Balance Index, HBI, explained here, is defined as the ratio between the comfortable heat balance of the body and the metabolic heat production (Castillo and Huelsz, 2017). The comfortable heat balance of the body is given by the algebraic sum of the metabolic heat production and the heat transfer between the body and the surrounding given by the mechanisms of radiation, convection and evaporation,

$$HBI = \frac{M - R - C - E}{M} \tag{1}$$

where M, R, C and E are the metabolic heat production, and the heat transfer by radiation, convection and evaporation, respectively, all expressed in (W/m^2). The following empirical expressions for R, C and E (Wang et al., 2011) are used,

$$R = C_1\left(T_s - T_r\right) \tag{2}$$

$$C = C_2 U^{3/5}\left(T_s - T_a\right) \tag{3}$$

$$E = C_3 U^{3/5}\left(P_s - P_a\right) \tag{4}$$

where T_s = 35 °C is the skin temperature, T_r (°C) is the mean radiant temperature, T_a (°C) is the ambient temperature, U (m/s) is the air velocity, P_a (10^2 Pa) is the partial pressure of water vapor and P_s = 56 $\times 10^2$ Pa is the vapor saturation pressure at T_s. The model constants are C_1 = 4.4 W/m^2°C and C_2 = 4.6 Ws$^{3/5}$/m$^{13/5}$°C . The factor C_3 for maximum evaporative capacity in Belding and Hatch (1955) has a constant value. In this work, the factor C_3 was modified for comfort evaporation by correlating results from the PMV comfort range (±0.5), resulting in $C_3 = 26.903 – 0.857T_a – 0.003RH$; RH where is the relative humidity. When the value of C_3 is less than zero, it is considered as zero. These expressions are based on the assumptions that all the latent heat of sweat evaporation is drawn from the body and the skin temperature, T_s = 35 °C, is constant. As the evaporation is only possible if $P_s > P_a$, if this condition is not fulfilled E = 0 in Eq. (4). Also, if the calculated value of $E < 0$, it is considered as zero. In this model the heat transfer by breathing is not considered. The heat transfer by this mechanism can represent up to 5% of the metabolic level considered in the present study (standing, light activity) and will represent a lower proportion for higher metabolic levels. As HBI is developed for hot climates, in the PMV calculation single layers of light weight clothing are considered, I_{CL} = 0.05 m^2°C/W = 0.32Clo.

In Table 1, the range of conditions covered by the empirical expressions (Eq. (2) - (4)) used for the calculation of HBI are shown. These range of conditions, based on Wang et al. (2011), allow a proper application in hot climates, as the climate studied in this paper.

Table 1. The range of conditions covered by the HBI, based on Wang et al. (2011).

Lower limit		Upper limit
65 W/m^2	≤ M ≤	327 W/m^2
21 °C	≤ T_a ≤	31 °C
0.25 m/s	≤ U ≤	10.00 m/s
0 %	≤ RH ≤	100 %
3 ×10^2 Pa	≤ P_a ≤	56 ×10^2 Pa

A zero value of HBI represents the neutral thermal condition, where the heat generated by the body (M) is exactly equal to the heat transferred to the surroundings with comfort evaporation. For this work, the range 0.2 ≤ HBI ≤ 0.2 is considered the comfort range. This range is obtained by correlating the PMV comfort range (0.5 ≤ PMV ≤ 0.5) with the HBI. HBI < 0.2 indicates that the body has an overdissipation greater than the 20%, with respect of M, causing a cold uncomfort. On the other hand, HBI > 0.2 signifies that the body has a subdissipation greater than the 20%, thus the body feels a hot uncomfort.

In order to evaluate the range for thermal comfort of the magnitude of the air velocity produced by natural ventilation, U is solved from Eq. (1) to Eq. (4),

$$U = \left[\frac{M\,(1 - HBI) - R}{C_2\,(T_s - T_a) + C_3\,(P_s - P_a)}\right]^{5/3} \tag{5}$$

As can be observed, U depends on HBI. Three magnitudes of U are distinguished: U_{min}, U_{neu} and U_{max}, for the *HBI* values of 0.2, 0.0 and 0.2, respectively. Thus $U_{min} \leq U \leq U_{max}$, represents the comfort air velocity range for a given activity (M value) and climatic conditions.

Windexchanger reference case

The windexhanger (WE) reference case has square-cross-section, one duct, four openings and flat roof. It is located on the center of a room roof. The WE has a height of 1.40 m measured from the roof, have a square-cross-section of 0.65 m in length and it is designed with a roof eave of 0.64 m as solar and rain protection. The interior dimensions of the room are W×D×H = 3.0×3.0×2.7m^3 (Fig. 1). The room has a square window at windward, 1.30 m in length, giving a wall porosity (opening area divided by wall area) of 17% (Etheridge, 2012), it is centered on the wall and its base is at a height of 0.90 m from the floor.

Experiments

The room with the WE reference case was experimentally tested by (Cruz-Salas et al., 2014) using a scaled model (1:25), as shown in Fig. 1. The scaled model was set in the test section of an open water channel (OWC) and Stereo Particle Image Velocimetry (SPIV) measurements were carried out. The OWC is 6 m long and has a test section of 1.0 $\times$ 0.315 $\times$ 0.41 m^3. The scaled model is made of transparent acrylic, with thicknesses of 6 mm for walls and room's roof, 9 mm for the floor, and 3 mm for the WE roof. The interior dimensions are $W \times D \times H$ = 12$\times$12$\times$10.8cm^3. The SPIV measurements were performed in the vertical central plane, as shown in Fig. 1b. In the OWC, an atmospheric boundary layer (open-terrain roughness profile) of a suburban area was reproduced. The mean velocity, U, and turbulence intensity, I, profiles were measured in the empty test section at the model position but without it, i.e. incident profiles. The obtained friction coefficient of the exponential law is α=0.29 and the aerodynamic roughness length z_0 is 0.06 cm (for full scale, 0.015 m). The incident profiles are used for a reliable validation study as recommended by (Blocken et al., 2008). A reference mean wind speed U_{ref} = 0.089 m/s (for full scale, 0.062 m/s) and a reference turbulence intensity of 20% were measured at the reference height z_{ref} taken as the external height of the room h = 12.3 cm (for full scale, 3.075 m). The experiments were made in water applying the dynamic similarity with the Reynolds number $Re = U_{ref}\, z_{re}/\nu = 1.23 \times 10^4$, where ν = 8.94 $\times 10^7$ m^2/s is the kinematic viscosity at the water temperature T_w = 25 °C.

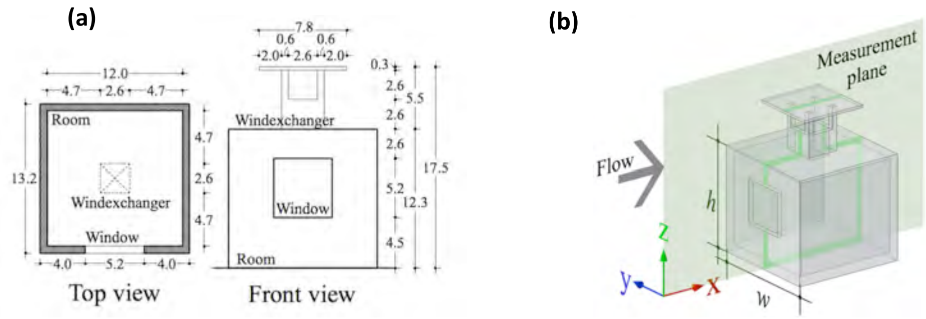


Figure 1. Model of the room with the windexchanger reference case. (a) Top and front view, units in centimeters; (b) Isometric view with the measurement plane and flow direction, where h = 0.123 m and w = 0.132 m are the external height and width of the room model, respectively.

CFD Validation

The present paper reports a CFD study performed with the commercial code COMSOL 5.1 (COMSOL 2013). This section presents the simulation model and settings for the validation of the room with the WE reference case. The settings are taken from a previous validation work (Castillo et al., 2014) using the experiments reported by (Cruz-Salas et al., 2014) and succinctly presented in previous section.

Model and settings

For the CFD simulations, the 3D steady RANS equations in combination with the shear-stress transport (SST) k-ω model are solved. The GMRES solver with MULTIGRID-SOR preconditioner is employed for velocity-pressure coupling, and the MULTIGRID-SCGS preconditioner is used for viscous terms of the governing equations (COMSOL 2013). The convergence criteria is assumed to be obtained when all the scaled residuals are equal or less than 10^{-4}.

Computational domain and grid

The computational domain with the room with the WE reference case is developed following the best guidelines by (Tominaga et al. 2008; Ramponi and Blocken 2012), its dimensions are $W_d \times L_d \times H_d$ = 0.315 × 2.346 × 0.41 m^3 (Figure 2a). A tetrahedral grid is created with 1,176,225 nodes (Figure 2b).

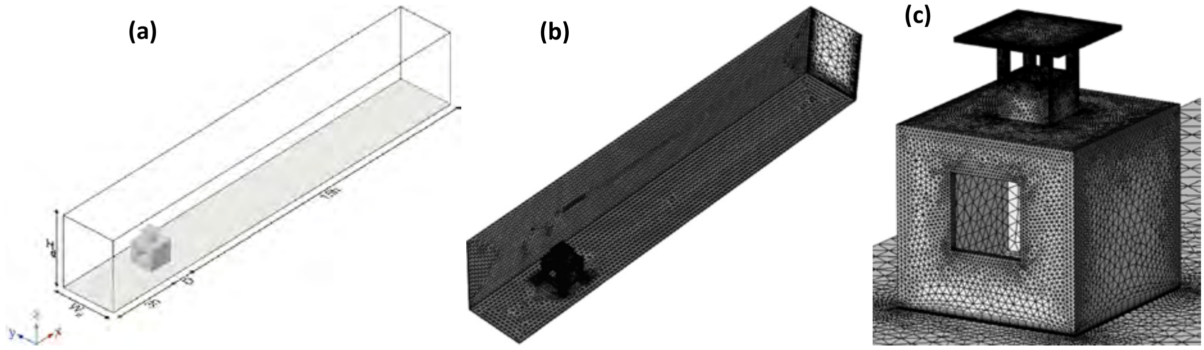


Figure 2. Computational domain with the model of the room with the WE reference case: (a) Perspective view with dimensions of the domain; (b) Perspective view of grid at bottom face (grid A with 1,176,225 nodes); (c) Isometric view of the room with the WE reference case.

Boundary conditions

The inlet boundary conditions are set according to the experimental velocity and turbulent profiles. The velocity profile is defined by the logarithmic law, $U(z) = (u^*_{ABL}/\kappa)\ln((z+z_0)/z_0)$, with the atmospheric boundary layer (ABL) friction velocity, u^*_{ABL} = 0.007 m/s, the von Karman constant, κ = 0.42, the roughness length, z_0 = 0.0005 m, and the height coordinate, z. The turbulent kinetic energy profile, $k(z) = (\sigma_u^2(z)+ \sigma_v^2(z)+ \sigma_w^2(z))/2$, is calculated from the standard deviation of each velocity component for x-direction, σ_u , for y-direction, σ_v , and for z-direction, σ_w. The turbulence dissipation rate and specific dissipation rate profiles are obtained, $\varepsilon(z) = u^{*3}_{ABL} /\kappa(z+ z_0)$ and $\omega(z) = \varepsilon (z)/C_\mu k(z)$, respectively, with the empirical constant C_μ = 0.09 (Tominaga et al. 2008). The standard wall functions (COMSOL 2013) are set at ground surface and at lateral walls. The zero static pressure is applied on the rear face of the domain. The free slip condition at the top boundary is used to simulate the air- water interface. In Fig. 3, the velocity profile and turbulent profiles, $k(z)$ and $\omega(z)$ at the inlet and incident building position in the empty domain are presented, showing that their streamwise gradients are negligible.

Validation

In Fig. 4, the experimental and CFD velocity vector fields at the central plane are shown, as well as the streamwise speed ratio, u/U_{ref}, along a horizontal line, L_h. The CFD simulations results show good agreement whit the SPIV experimental results. The averaged difference of stream-wise speed ratios is lower than 10%.

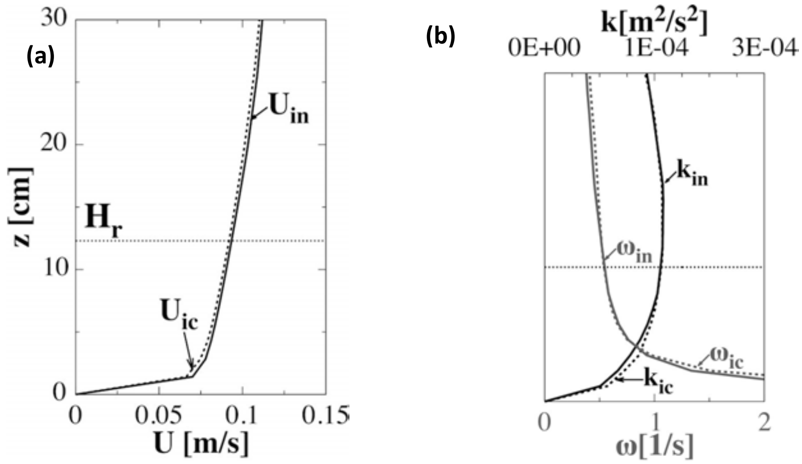


Figure 3. Vertical profiles of (left) the mean velocity, U; (right) the turbulent kinetic energy (dark line), k, and the specific dissipation rate (gray line), ω, at the inlet (continuous line) and at the incident building position (dashed line) in the empty domain. The subscripts in and ic refer to inlet and incident, respectively. The height of the model (h) is 0.123 m.

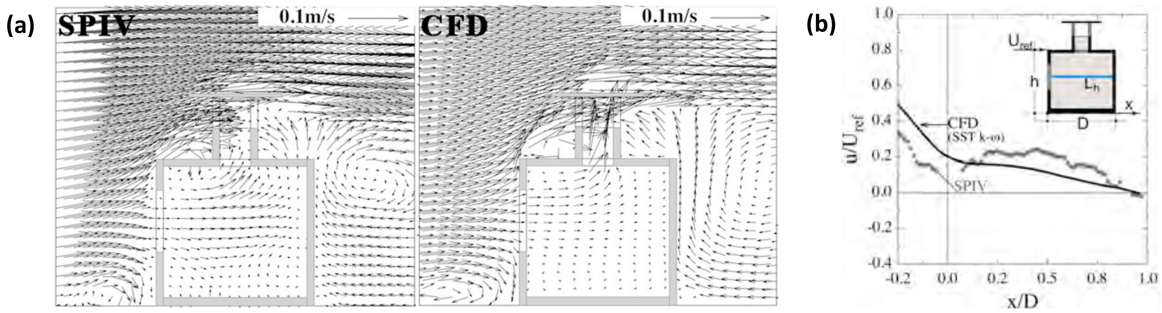
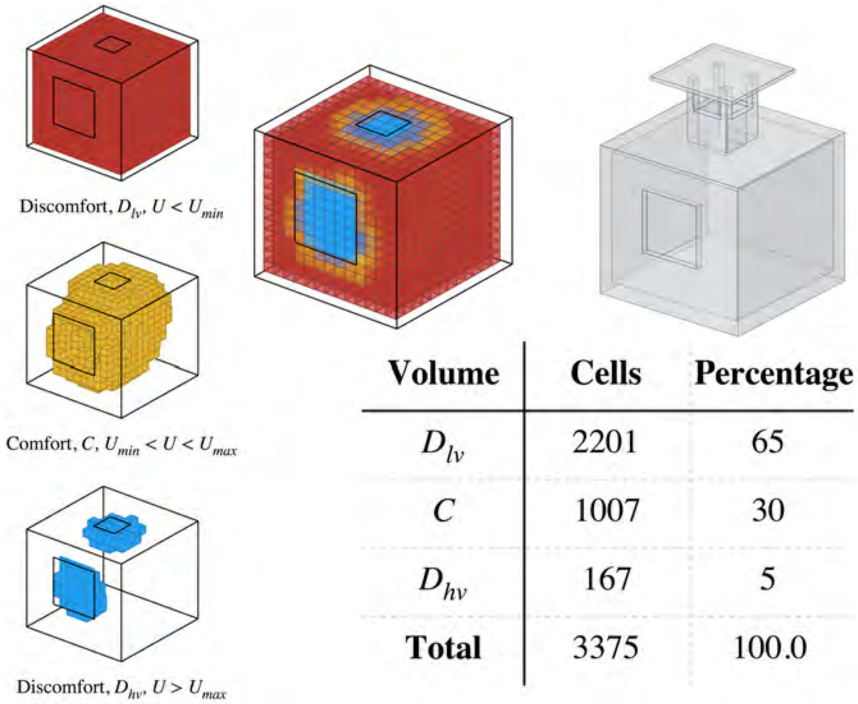


Figure 4. Experimental (SPIV) and numerical (CFD) results: (a) Velocity vector field at the central plane and (b) Streamwise speed ratio u/U_{ref} along the central line L_h.

Application example of HBI

To evaluate the thermal comfort produced by natural ventilation inside the building by using the HBI, the computational parameters and settings presented in Section CFD Validation are employed. Note that, the simulations done in that section reproduces the experimental conditions, in which the building is scaled 1/25. To obtain direct results in full scale, the domain and the building are rescaled to full scale by maintaining geometric similarity. For the application example, the numerical results are averaged over the last one hundred iterations to obtain a reliable steady numerical solution of an intrinsically unsteady flow phenomena performed with a RANS turbulence model. The U_{ref} is taken from the weather data for calculating the inlet velocity profile and it is used in the kinematic similarity calculations. The interior volume is discretized in 3375 cells of which the air velocity magnitude is obtained. Then, the HBI is calculated with the following data: Radiant temperature, T_r; Ambient temperature, T_a; Relative humidity, RH; Reference air velocity, U_{ref}; and Metabolic heat production, M.

The HBI application example is performed with the averages of the maximum values of the hottest and most humid month (August) in the Temixco city located in Morelos, Mexico. These conditions are U_{ref} = 3.5 m/s (the reference air velocity at h = 2.25m building height), $T_r = T_a$ = 27 °C and RH = 80%. The $U(z)$ from the real scale are modeled as inlet boundary condition, in the validated numerical model, by applying the dynamic similarity with $Re = U_{ref} h/\nu = 6.85 \times 10^5$. Fig. 5 shows the comfort evaluation by natural ventilation of the building with a window and a windexchanger (Fig. 1), applying Eq. (5) and considering a metabolic heat production of $M = 93$ W/m^2 = 1.6 met (light activity). The interior volume can be zoned as: discomfort by low ventilation (hot discomfort), D_{lv}, comfort, C, and discomfort by high ventilation (cold discomfort), D_{hv}. In this example, the percentages of D_{lv}, C, and D_{hv} zones are 65%, 30% and 5%, respectively, indicating that for these climatic conditions the cross ventilation in this specific building is not enough to provide thermal comfort in most of the building interior.



Volume	Cells	Percentage
D_{lv}	2201	65
C	1007	30
D_{hv}	167	5
Total	3375	100.0

Figure 5. Evaluation of the comfort by natural ventilation of a building with cross ventilation. The interior volume is zoned as: discomfort by low ventilation, D_{lv}, comfort, C, and discomfort by high ventilation, D_{hv}. The range $U_{min} \leq U \leq U_{max}$ refers to the comfort air velocity range.

Discussion and conclusions

This paper provides an application example of this methodology using numerical simulations with CFD. The results of the application example only are valid for the described values of the building geometry, radiant temperature, ambient temperature, relative humidity, reference air velocity and metabolic heat production.

The HBI gives the comfort air velocity range, which is useful to calculate the well-ventilated percentage of an indoor space for a specific climate condition in hot climates and to assess the effect of a given strategy for natural ventilation. This can be done with CFD results or with experimental ones. Further research should be done to include the thermal adaptability in the HBI mathematical model.

Acknowledgements

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Application of Experimental and CFD Methods as an Educational Approach for Evaluation of Natural Ventilation to Improve Hygrothermal Comfort

José Roberto García Chávez[1], Guilebaldo Tolentino[2], René Tolentino[2] and Andrés García[3]

[1] Metropolitan Autonomous University, Graduate Programme. Mexico City, Mexico
joserobertogsol@gmail.com

[2] National Polytechnic Institute. Mexico City, Mexico. Laboratory of Applied Thermal and Hydraulic Engineering gte@maya.esimez.ipn.mx

[3] University College Mayor of Cundinamarca, Bogotá, Colombia
amgarciat@unal.edu.co

Abstract: The supply and control of natural ventilation is essential in buildings and plays an important role in their design for hygienic reasons and for providing occupant´s hygrothermal comfort and for achieving energy savings and improving the environment. The objective of this research work was focused on the integration of experimental and Computer Fluid Dynamics (CFD) methods to visualize, measure and simulate the behaviour or natural ventilation in and around buildings aimed at providing researchers, students, and building practitioners with useful sustainable educational design tools from conceptual to documentation stages in architectural and urban projects. The methodology consisted of using physical scale models to analyse and evaluate air movement patterns experimentally. The utilization of wind tunnels provided two useful components: Visualization of airflow patterns in and around buildings and calculation of wind pressures and speeds. These two components were complemented with CFD simulations also for visualization and calculating pressures and wind velocities. The results indicated that the suitable use of experimental and CFD simulation techniques for analysis and evaluation of natural ventilation are useful tools aimed at achieving a significant reduction on energy consumption in buildings whilst improving the occupant´s hygrothermal comfort and the environment, meant to promote sustainability and to contribute to mitigate global climate change.

Keywords: Natural Ventilation, buildings, hygrothermal comfort, physical scale models, CFD, energy savings.

Introduction

At present, most modern buildings incorporate architectural styles and materials that ignore the local climatic conditions as well as its cultural and traditional factors. This is the predominant case of many contemporary buildings. As a result, such buildings are highly dependent on mechanical and electrical systems to control the indoor environment. This situation causes the consumption of large quantities of energy and thus high running costs for both artificial lighting and air-conditioning systems (HVAC), associated with problems of occupants' discomfort, both hygrothermal and visual, among others. Consequently, people who live in air-conditioning buildings have to pay huge energy bills and confront serious maintenance and economic problems during most seasons. Furthermore, those people who cannot afford to have mechanical ventilation or HVAC, their building interiors become severely unbearable and their health is seriously affected. The lack of ambient comfort conditions in commercial buildings is also a burden for people's efficiency, productivity and competitiveness and these issues are crucial for promoting and encouraging economic development. The use of energy in buildings has a direct relationship and impact on the environment; the burning of fossil fuels and their emission to the atmosphere due mainly to anthropogenic activities have provoked a severe damage in our planet.

At global level, buildings consume nearly half the annual energy for heating, cooling, water heating, and cooking, among other necessities. In terms of electricity consumption, almost seventy-five percent is used to operate and maintain buildings. Energy used in buildings comes mainly from the burning of fossil fuels, which provokes the emission of greenhouse gasses (GHG), and consequently global warming and climate change, among other consequences. The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2014) confirms and ratifies the necessity for immediate and sustainable actions to reduce the burning of fossil fuels aimed at a complete phasing out by around 2050. Buildings play an important role for this to come about, as they are responsible for almost half of the CO_2 emissions. This Report also states that it is this sector, which can be an effective turning point in the earth´s climate systems to mitigate the environmental damage, by transforming the way buildings are designed, built and operated. The approach to make this possible is by applying sustainable design in buildings by providing the required knowledge regarding its principles, concepts and methodology to implement appropriate design strategies compatible with sustainability.

One strategic area for this approach to be applied is in providing effective natural ventilation in buildings to achieve the maximum possible hygrothermal comfort conditions for the occupants at the minimal consumption of energy. The objective of this research is focused on the integration of experimental and simulated fluid dynamics techniques (CFD) in buildings, aimed at providing sustainable educational design tools for schools of architecture, and engineering, as well as design alternatives for engineers and building practitioners. Methods for evaluating natural ventilation in buildings include mathematical and computer models (CFD) as well as experimental procedures (wind tunnels). Certainly, three-dimensional physical simulators, in the form of wind tunnels are practical and useful tools for studying air movement patterns in and around buildings experimentally in architectural and urban projects. The utilization of wind tunnels can provide two components: Visualization of airflow patterns in and around buildings and measuring of wind pressures and speeds.

Natural Ventilation as an Effective Passive Cooling Technique to Provide Building Occupants with Hygrothermal Comfort Conditions

Previous studies have demonstrated that the implementation of passive cooling techniques in buildings with high thermal cooling loads is a promising alternative to contribute to solve great external and internal heat gains and high energy consumption patterns, occupants' thermal discomfort and health conditions whilst reducing environmental damage problems (Blondeau et al., DeKay, et al. 2014; García Chávez, 2015; Givoni, 1994 Santamouris et al, 1996, Lechner, 2009; Kwok et al., 2014).

Natural ventilation is one of the passive cooling techniques which can be applied as a powerful bioclimatic strategy to provide hygrothermal comfort to occupants of buildings. Natural ventilation can cool interior spaces by displacing the hot inside air with cooler outside air. This displacement can be obtained naturally by wind induced pressure or by temperature and pressure differences through the thermal stack effect. Therefore, suitable ventilation strategies in buildings can contribute to occupants' benefits in two main areas: Health and Hygrothermal Comfort. Depending on the climatic conditions and parameters as well as on occupant's comfort requirements, windows can be open throughout the night to obtain effective Nocturnal Ventilative Cooling.

In this research, natural ventilation strategies were selected for investigation applying experimental techniques in a wind tunnel and simulation CFD techniques to assess the performance of typical building configurations, aimed at providing sustainable educational design tools for schools of architecture and engineering, as well as design alternatives for engineers and building practitioners. The results of this research indicated that the suitable implementation of these techniques in the design and construction of buildings in different climates could lead to a reduction on energy consumption whilst improving the occupant´s hygrothermal comfort and the environment.

Experimental Performance of Convective Cooling on 3D Scale Models Using a Wind Tunnel

Experimental evaluation of the performance of air movement using wind tunnels have been identified its usefulness for assessments of naturally ventilated structures (Tolentino et al, 2008). This work investigated the potential of natural ventilation techniques in typical building configurations aimed at providing hygrothermal comfort conditions in building´s occupants using perplex 3D physical scale models built for visualization of air movement and measuring speeds and wind pressures (using a hot wire anemometer), and introduced in the wind tunnel (Figures 1, 2 and 3).

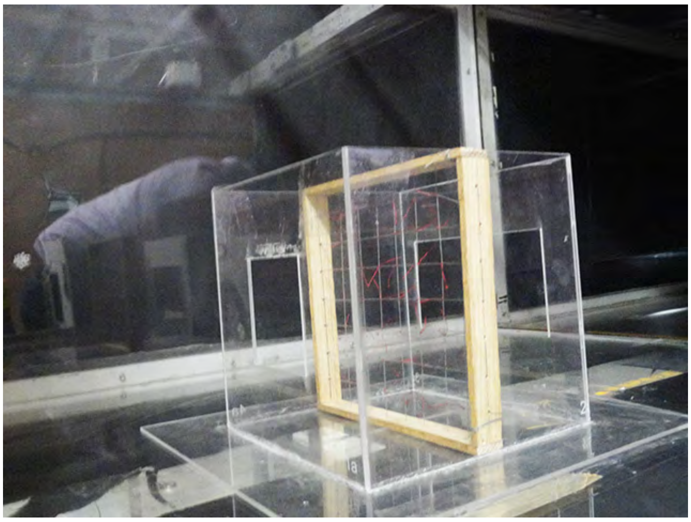

Figure 1. Visualization technique using a boundary frame with thin cords of a 3D model in the wind tunnel operating at a speed of 2 m/sec

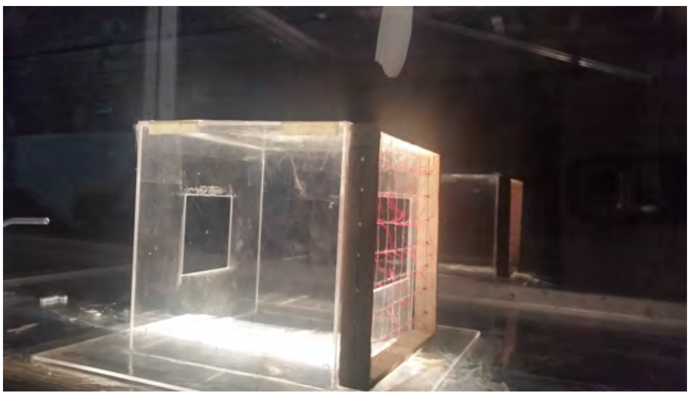

Figure 2. Visualization technique using a boundary frame with thin cords of a 3D model in the wind tunnel lit background

Figure 3. Scale 3D model for visualization technique and using a hot wire anemometer for measuring pressure and wind speed

The wind tunnel utilized for the experimental work is located at the Laboratory of Applied Thermal and Hydraulic Engineering in Mexico City. It is an open circuit wind tunnel with a suction and pressure test section. The airflow is generated by a centrifugal fan driven by a 74.6 kW (100 hp) electrical motor controlled with a variable frequency drives, to get different velocities in both test sections. The highest wind velocity in the suction test section is 65 m/s and this velocity depends of environmental conditions like temperature, barometric pressure and humidity, among other ambient factors, measured concurrently at a meteorological station in the site. The experimental equipment has a rectangular cross test section of 0.8 meters by 0.6 meters, a variable length of 4.0 meters. The wind tunnel has a settling chamber to have a good flow quality in the test section. The components are a bell mouth follow by a honeycomb grid with a cell size of 10.5 mm, thickness of 0.2 mm and a length of 85 mm. Once the flow passes through the honeycomb grid, there are five screens of 20 meshes, wire diameter of 0.23 mm and an open ratio area of 0.67, to reduce the velocity fluctuation in the test section. At the end of the settling chamber, there is a contraction with an area ratio of 9:1, a length of 1,680 mm manufactured with plywood. The flow quality in the test section was verified by measurement of velocity profile, turbulence and boundary layer in the test section using a hot wire anemometer.

Figure 4. Open circuit and suction wind tunnel used during the experiments

Methodology of the Experimental Work

During the experiments, the instrumentation used to get the velocity distribution was a constant temperature hot wire anemometer, 90C10 model. The probe 55P11 was used to measure the velocity and turbulences intensity. The probe was calibrated in a velocity range from 0.5 m/s to 50 m/s. Frequency and time sample were 30 kHz and 30 s for all measurements. The probe was moved by a three dimensional traverse system. The traverse is outside the tunnel in order to avoid the blockage effect. Pressure, temperature and humidity relative were also measured during the experiments by means of a local on-site meteorological station. Data velocities collected were reduced to get the turbulence intensity [%] in every point measured. For steady flow the turbulence intensity (Tu) was computed with the ratio of root mean square velocity and local time average velocity, shown in Equation 1.

$$Tu = \frac{u_{RMS}}{\overline{U}} \times 100 \tag{1}$$

The root mean square velocity (uRMS) in Equation 1 is shown in Equation 2:

$$u_{RMS} = \left[\frac{1}{N} \sum_{i=1}^{N} \left(U_i - \overline{U} \right)^2 \right]^{1/2} \tag{2}$$

During the first set of the experimental work, convective cross ventilation was assessed in the two scale models. Different visualization techniques were applied and subsequently pressure and wind speed were measured. A third scale model was subsequently evaluated using also visualization techniques and measurements of pressure and wind speed. This scale model included evaluation of direct wind and by means of the differences in temperature and pressure of the air, also called buoyancy or “stack effect” or “chimney effect”. The effectiveness of both convective cross ventilation and stack effect were demonstrated in the three scale models investigated (Figures 5, 6 and 7).

Figure 5. Physical 3D scale model of a real educational building for experimental assessments in the wind tunnel


Figure 6. Physical 3D scale model of a real educational building in the wind tunnel

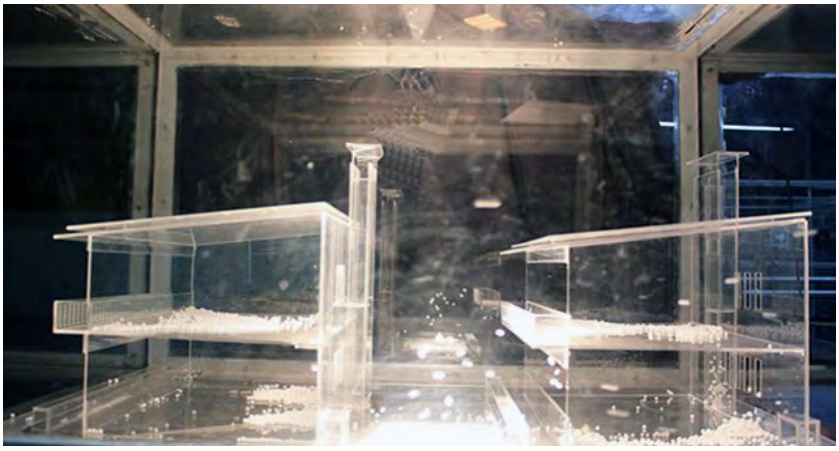
Figure 7. Physical 3D scale model of a real educational building in the wind tunnel operating, showing visualization technique of small polystyrene spheres

Air velocities and wind pressures were monitored in three measuring points located within the physical scale models at 120 cm height. Hot wire anemometers were used for the measurements in the physical model whilst maintaining the required velocity, controlled by the electronic speed system of the wind tunnel. For visualization of air patterns inside the physical model, the techniques used to identify the air movement was by means of a a) Section frame with thin wires; b) Small polystyrene spheres; and c) Smoke flux fine at different heights to provide a complete scan of the scale models. High resolution digital video and fixed pictures were applied to capture air movement pattern images (Figures 5 and 6). C to 23 ° C; the relative humidity varied from 62% to 63%, and the atmospheric pressure was stable at 79.8 kPa. The indoor air speeds within the model were measured as a percentage, relative to the external wind velocity at window level. Since the physical model tested has no curved surfaces, the air flux was discharged from the borderlines and thereby the results became independent of the Reynolds Number. Then, this outcome is a valid approximation, as the comparisons of velocity percentages of the models evaluated relative to the air flux in a 1: 1 real case, and therefore, it was a reliable parameter for analogy in this research work.

Computer Fluid Dynamic Assessments and Results

CFD techniques were applied in the three models investigated in this research. The results of the CFD analysis have shown a close approximation of the performance of air movement both outside and inside the analysed models (Figures 8 and 9). In model N1 model (for cross ventilation analysis), it can be seen an increase of air velocity inside the space. In model N2, with a 2:1 ratio, i.e. greater outlet opening relative to the inlet opening, it can be observed a more uniform upwards widespread air movement useful to promote heat gains and to dissipate polluted indoor airborne particles of an architectural space, even though air velocity is not increased. In model N3 (a real school building simulated), the performance of natural ventilation and the extracted chimney thermal convective effect is clearly observed, driving exhausting indoor air (hot and/or polluted air) towards the outside, at a greater air speed, not as large as in model N1 though, significant for the conditions of this evaluation.

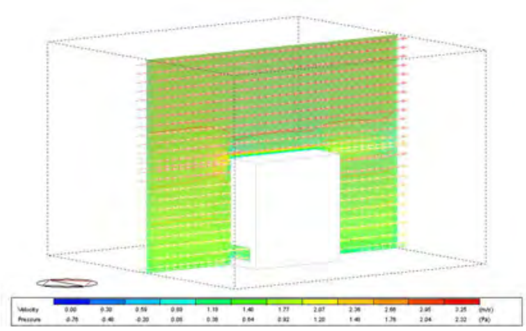

Figure 8. Model N2 Cross ventilation with Inlet (lower) and Oulet (upper) Openings. Ratio 1:2, using CFD to visualize and compute air velocity and pressure

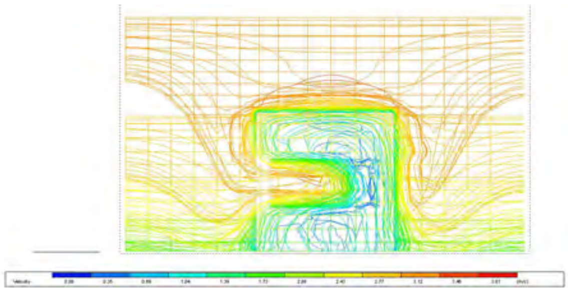

Figure 9. Model N1. Cross ventilation using CFD to visualize and compute air velocity and pressure

Conclusions

The experimental work demonstrated the benefits of using natural ventilation for providing hygrothermal comfort replicated in real buildings. When comparing the cross ventilation design alternatives with wind direction perpendicular to the façade, average percentages relative to the external wind velocities were reduced within a range from up to 21%.

It was found that when wind direction was at 45°, the air movement inside the models was optimizes, increasing an average of 36% relative to the direct cross ventilation design alternative. As to CFD simulations, this method offers researchers, architects, designers and building practitioners, an essential tool for obtaining useful information of architectural projects about the air movement behaviour inside and outside the buildings, particularly since different strategies and systems can be analysed and evaluated to optimize the design and performance of the project. Furthermore, the results can be oriented to achieve a bioclimatic and sustainable building which in turn can contribute to improve the ambient comfort conditions and health of the occupants as well as the environment and the quality of living for the present and future generations.

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Indoor Temperature Variation with Different Roof Materials and Natural Ventilation

Patricia R Drach[1,2,3]

[1] Architecture and Urbanism Department, School of Industrial Design, State University of the Rio de Janeiro – DAU/ESDI/ UERJ, Rio de Janeiro, Brazil, pdrach@esdi.uerj.br;
[2] Post-graduate Program in Urbanism, School of Architecture and Urbanism, Federal University of Rio de Janeiro – PROURB/FAU/UFERJ, Rio de Janeiro, Brazil;
[3] Urban Engineering Program, Federal University of Rio de Janeiro - PEU/POLI/UFRJ, Rio de Janeiro, Brazil, patricia.drach@gmail.com

Abstract: This work involves experiments using subroutines developed by the author in Fortran language to calculate heat and mass transfer, and ventilation. The simulations were done to check the results of the influence of the application of different materials on a flat roof associated to passive ventilation. The target of this paper is to evaluate the use of subroutines developed to show air temperature changes, the heat transfer through a flat roof and the ventilation on a small prototype. The experiments conducted involved predictable results and that is exactly why they were suitable to check the performance of the subroutine. It is relevant to mention that the heat transfer through a flat roof was checked including a solar gain factor, which changes during the simulation using the subroutines, according to the hour of day (hourly from 7a.m. to 5p.m). The analysis started by solving the air-circulation problem to determine the wind fields, using a mixed stabilized finite element method, like Petrov-Galerkin, applied to the full Navier-Stokes equations. The thermal problem is analyzed through the SUPG – Streamline Up-wind Petrov-Galerkin stabilized finite element method. Computational simulations allow for testing low cost operational interferences before implementing a project.

Keywords: computational modelling, finite element method, indoor temperature, passive ventilation

Introduction

In this work, we resume the research in which the focus was to the development of subroutines in Fortran language, by the author, to calculate heat and mass transfer and ventilation. The test of its capacity of simulation was geared towards the small issues that can contribute with alternatives to deal with indoor heat, based on reduced, economical and environmentally friendly costs. Seeing that the city of Rio de Janeiro, Brazil, is a warm tropical climate city it is important to block the entrance of heat into buildings or at least act to minimize their input. The high costs of introducing and maintaining refrigeration systems are not only prohibitive for the majority of the population in a city such as Rio de Janeiro, but costly for the environment as well.

This hypothetical study is set in Rio de Janeiro city, where the strong heat sometimes associated with the bad location of openings in the buildings and the choice of materials can cause thermal distress. In the old areas of the city, a kind of construction called “vila” can be found, i.e., a dead end small street with only one inlet/outlet. Houses built in these “vilas” tend to lack sufficient space around them.

Besides scarce ventilation, this hypothetical model also receives solar radiation directly on its roof. The interference of incident solar radiation on a flat roof was considered; taking into account its respective materials. The thermal changes between outdoor and indoor environments include a solar gain factor related to three specific hours; 7 a.m., 12 a.m. and 4 p.m. Three openings location position were evaluated to check the best answer in terms of ventilation. In relation to the roof four scenarios were tested: cement roof's top layer in natural colour; cement roof's top layer painted in a light colour, like white. It is known that this kind of change is able to reduce heat gains besides being a cheap and easy alternative; fiber cement roof tile, formed by only one layer and fiber cement roof tile painted in white. This material (fiber cement), even not being a healthy option, is one of the most widely used materials for poor inhabitants, maybe because it is economical and easy to apply. Its application uses less wood and does not require a complex structure for its attachment.

The computational analysis started by solving the air-circulation problem to determine the wind fields, using a mixed stabilized finite element method, like Petrov-Galerkin, applied to the full Navier-Stokes equations. The thermal problem is analyzed through the SUPG – Streamline Up-wind Petrov-Galerkin stabilized finite element method.

This study presents the results of tests including both opening locations and roofing materials. The analysis of the association of both aspects, allows us to deal with the issue of keeping heat out of indoor spaces, in hot weather regions.

These results are important to understand if the subroutines in Fortran language are able to present the expected results.

Methods

The air-circulation and thermal problem are analyzed through a mixed stabilized finite element method (like Petrov-Galerkin) and the SUPG (Streamline Up-wind Petrov-Galerkin), a stabilized finite element method (Drach, 2007; 2010a). The subroutines were developed (Drach, 2007) in Fortran language and were based on the one DLearn by T.J.R. Hughes (in textbook: The Finite Element Method).

Mathematical Formulation

The problem of air circulation and heat transfer was modelling through mass, momentum and energy conservation equations. Assuming incompressibility, the known mathematical formulation for the general problem can be written as: Find $\mathbf{u}$, p and θ satisfying the following system,

$$div\ (\mathbf{u}) = 0,\ \text{in}\ \Omega\times[0,\mathrm{T}], \tag{1}$$

$$\rho\frac{\partial\mathbf{u}}{\partial \mathrm{t}} + \rho\ (\nabla\mathbf{u})\mathbf{u}\ \text{-}\ 2\mu\ div\ \varepsilon\ (\mathbf{u}) + \nabla \mathrm{p} + \rho\mathbf{g}\beta(\theta-\theta_\infty) = 0,\ \text{in}\ \ \Omega\times\left[0,\mathrm{T}\right], \tag{2}$$

$$\rho c_p\frac{\partial\theta}{\partial t} + \rho c_p\mathbf{u}.\left(\nabla\theta\right) - k\ div\ \nabla\theta = 0,\ \text{in}\ \ \Omega\times\left[0,\mathrm{T}\right]\ , \tag{3}$$

$\nabla\mathbf{u}.\vec{\mathbf{n}} = 0$ in $\Gamma_v\times\left[0,\mathrm{T}\right]$, $\mathbf{u}(\mathbf{x},\mathrm{t}) = \bar{\mathbf{u}}(\mathbf{x},\mathrm{t})$ in $\Gamma_u\times\left[0,\mathrm{T}\right]$, $\mathbf{u}(\mathbf{x},0)=\mathbf{u}_0$ in $\Omega\times\left[0,\mathrm{T}\right]$, $k\nabla\theta.\vec{\mathbf{n}} = 0$ in $\Gamma_d\times\left[0,\mathrm{T}\right]$, $\theta(\mathbf{x},t) = \bar{\theta}$ in $\Gamma_c\times\left[0,\mathrm{T}\right]$ and $\theta(\mathbf{x},0) = \theta_o(\mathbf{x})$ in Ω.

where: $\mathbf{u} = (\mathbf{x},t)$ is the velocity vector, p $=(\mathbf{x},t)$ is the pressure, $\theta = \theta(\mathbf{x},t)$ is the temperature, μ is the viscosity, ρ is the density, k is the thermal condutivity, θ_∞ is the reference temperature, $\vec{\mathbf{n}}$ is the normal vector, c_p is the specific heat, β is the coefficient of thermal expansion, $\mathbf{g}$ is the gravity vector, $\varepsilon(\mathbf{u}) = \frac{1}{2}\left(\nabla\mathbf{u} + \nabla\mathbf{u}^T\right)$ and Ω is the bounded domain with boundary $\Gamma = \Gamma_u \cup \Gamma_v = \Gamma_c \cup \Gamma_d$ with $\Gamma_u \cap \Gamma_v = \Gamma_c \cap \Gamma_d = \varnothing$ and the time $t \in [0,\mathrm{T}]$.

The term $\rho\mathbf{g}\beta(\theta - \theta_\infty)$ allows the coupling of the air circulation and the heat transfer problems.

Methods

For the air circulation problem, the numerical solutions are here obtained by a stabilized mixed finite element method, Petrov-Galerkin type method (Franca and Frey, 1992), as in Drach (2007; 2010). This method allows us to deal with the difficulties that come from the first equation system, Equations (1) and (2): the difficulty in constructing approximation spaces for problems with internal constraint; non–linearities of the convective type and numerical instabilities when advection effects are dominant. In the case of a heat transfer problem a stabilized finite element method was implemented – Streamline Up-wind Petrov-Galerkin -SUPG (Brooks and Hughes, 1982).

Simulations

A 2D computational approach was used in this work, but it can be extended to a 3D-by-layers scheme and also to a 3D full approximation, since the mathematical formulation poses no restriction to any dimension (Drach, 2010).

The prototype, here, is a module built in a narrow street. This kind of construction was very common, in the beginning of the 20th century, in Rio de Janeiro city. These houses are usually very small and have no space around them. Besides insufficient ventilation, this hypothetical model receives solar radiation directly, so the interference of incident solar radiation on a flat roof was also considered in the model, taking into account its respective materials (Figure 1).

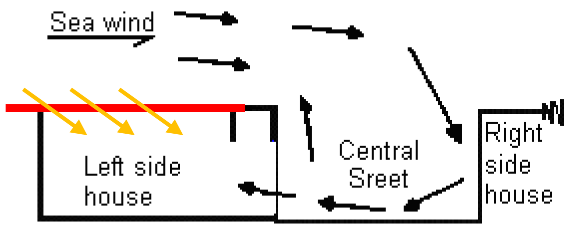
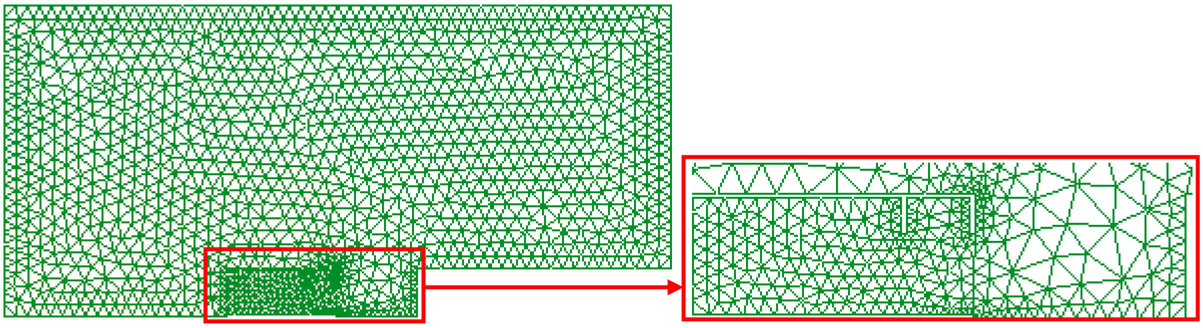


Figure 1. Prototype and the narrow street.

The model used deals with ventilation within openings and closed spaces, with possible leakage not being considered. The meshes generated for the experiments were composed by linear triangular elements which have collective dimensions that comprise areas bigger than the ones in the plants (Figure 2). The boundary conditions are imposed on their borders, so, the velocities and the temperatures at the entrances are considered to be unknowns and could be determined by the solution of the problem. In Figure 2, mesh and its detail can be observed.



a) b)

Figure 2. Original project whole mesh (a) and its details (b).

Boundary and initial conditions

The boundary conditions adopted for outdoor wind were 1 m/s, in order to make possible to test the situation for low velocity of air. This wind velocity corresponds to a breeze, according to the Beaufort scale, used in time forecast, and reflects the worst condition for ventilation in hot tropical climate. For the initial conditions was selected the outdoor temperature of 29ºC corresponding approximately to the average temperature in March in Rio de Janeiro city (Instituto Nacional de Meteorologia – INMET). For indoor temperature, 31ºC was considered the standard temperature. The sketch in Figure 3 shows the boundary and initial conditions adopted. The arrow on the figure top indicates outdoor wind direction and intensity. The same conditions were imposed to all experiments to make it possible to compare them (Drach, 2010b; 2011).

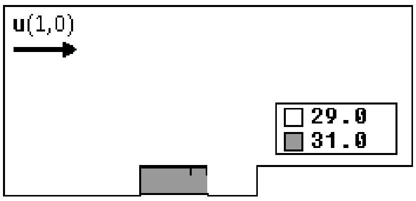


Figure 3. Boundary and initial conditions adopted for the experiments.

Solar radiation

To take into account the interference of the incident solar radiation and of the roof material on indoor temperatures, a temperature value was prescribed for the roof's surface outline that was defined based on the studies of Frota and Shiffer (Frota and Shiffer, 1988) and adopted previously in Drach (Drach, 2007). The calculation of the thermal flux intensity was made by the equation:

$q = K(t_e + \frac{\alpha Ig}{h_e} - t_i)$, where K is the global coefficient of thermal transmission, t_e is the outdoor temperature, t_i is the indoor temperature, α is the solar absorption coefficient of the material and h_e is the coefficient of superficial thermal conduction. Ig is the global intensity of incident solar radiation, with values that are fixed and related to the location, position and schedule. The solar earnings were represented by the term $\frac{K\alpha Ig}{h_e}$ and the factor of solar earnings by: $\frac{K\alpha}{h_e}$. The coefficient of superficial thermal conductance (h_e) values were adapted from Frota and Shiffer (Frota and Shiffer, 1988) and their fixed values take into account whether the walls position (vertical or horizontal) and, still, whether the flow (ascending or descending). The construction of the global coefficient of thermal transmission was also in agreement with that one given by Frota and Shiffer (Frota and Shiffer, 1988).

$\frac{1}{K} = \frac{1}{h_e} + \sum_{j=1}^{n} \frac{l_j}{k_j} + \frac{1}{h_i}$, where 1/ h_e and 1/ h_i are the outdoor and indoor superficial thermal resistances, respectively. For the case of walls composed by different materials, to each wall thickness (l) the thermal conductivity (k) of the respective material is associated and, j = 1…n, being n the number of materials of which the wall is composed.

The equations of the heat transfer through the flat roof were coupled to the subroutine developed. During the simulation process, the global intensity of incident solar radiation (Ig) was changed according to the day hour (hourly from 7a.m. to 5p.m).

Materials

For the experiment, construction materials that are common in Brazil were adopted, with the intention of checking if it would be possible to choose the one which impairs heat gains, more efficiently. The original test was done with cement roof's top layer in natural colour. The first change proposed was to paint the cement roof's top layer with a light colour, such as white. It is known that this kind of change is able to reduce heat gains and is also a cheap and easy alternative. On the third experiment, the adoption of fibre cement, formed by only one layer, was tested. Finally, the fourth test was done by painting in white the fiber cement roof tile (Drach, 2011). This material is one of the most widely used materials for poor inhabitants, maybe because it is cheap and easy to apply. Its application uses less wood and does not require a complex structure for attachment. Table 1 presents the layers that form the four covering tested, and Figure 4 shows the layers.

Table 1. The layers that form the four roofs tested.

Layer	Cement roof 1 Material – CR1	Cement roof 2 Material – CR2	Fiber cement roof 1 Material – FCR1	Fiber cement roof 2 Material – FCR2
l1	dark waterproof (no paint)	light waterproof paint	--------	light waterproof paint
l2	concrete with expanded clay	concrete with expanded clay	Fiber cement	Fiber cement
l3	armed concrete	armed concrete	--------	--------
l4	painted roughcast	painted roughcast	--------	--------

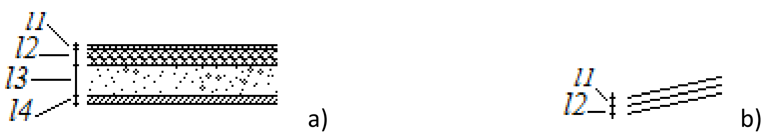


Figure 4. Layers that form the cement roofs; (a) first and second experiments, (b) third and fourth.

Using light colours to paint the roof can be one of the cheapest solution to decrease the heat transfer.

Opennings

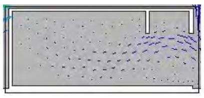
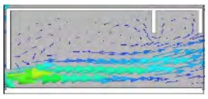
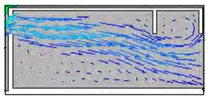
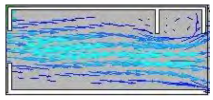
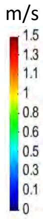
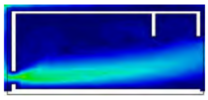
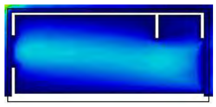
Four configurations were checked: one without cross ventilation (WO) and three others introducing cross ventilation - low (LO), high (HO) and middle (MO) opening - in order to find the coolest scenario.

Results and Discussion

Ventilation

The results for ventilation are presented in velocity vectors and in terms of contour fill of |**u**| in a colour scale (Table 2) for each opening's configuration.

Table 2. Results presented in terms of velocity wind field: a) WO, b) LO, c) HO and d) MO.

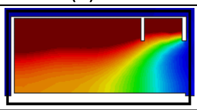
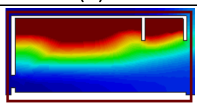
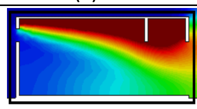
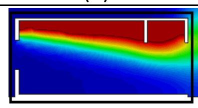
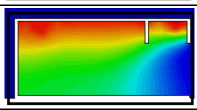
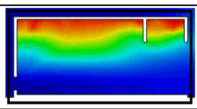
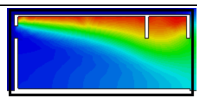
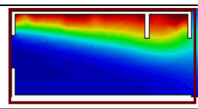
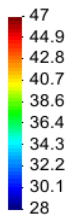
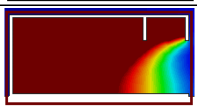
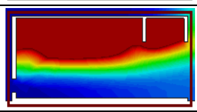
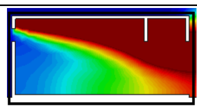
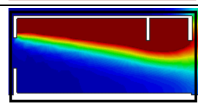
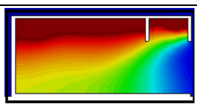
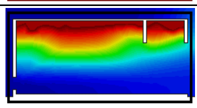
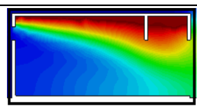
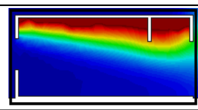
	(a) WO	(b) LO	(c) HO	(d) MO	
Wind Field - *Vector*					
Contour fill of |**u**|					

From the images (Table 2), it is possible to observe the interference of the opening location in wind field. The scenario without cross ventilation, as expected, presents the poor ventilation inside the module. The introdution of openings in a cross ventilation way, as in Drach (2010b), was able to increase indoor ventilation through all experiments. The introduction of Low Openning – LO promotes an intensification of air circulation. MO presents better distribution, if compared with LO and HO. The results presented in MO show a light tone which resulted in the occupation of 'more than half' of the internal space of the module.

Air Temperature

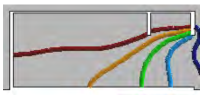
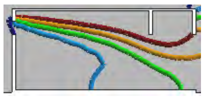
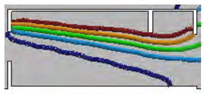
The thermal changes between outdoor and indoor environments include a solar gain factor related to two specific hours; 12 a.m. (Table 3) and 4 p.m. (Table 5).

Table 3. Results presented in terms of air temperature at 12 p.m.: a) WO, b) LO, c) HO and d) MO.

	(a) WO	(b) LO	(c) HO	(d) MO	**Scale**
CR1					Air Temperature - °C
CR2					
FCR1					
FCR2					

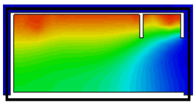
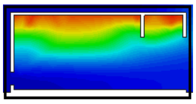
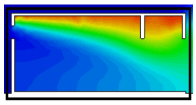
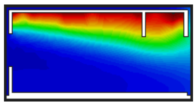
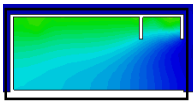
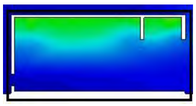
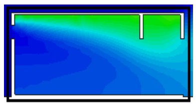
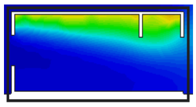
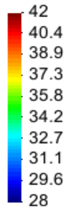
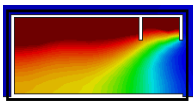
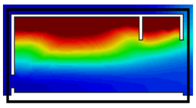
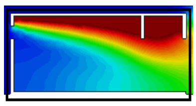
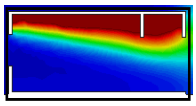
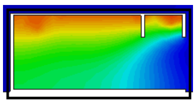
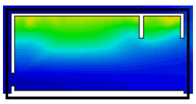
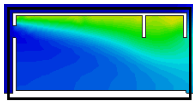
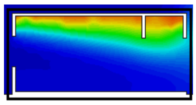
The results related to midday present temperatures above 47 °C near the ceiling. Originally, the buildings in these regions had a much higher ceiling, which caused these temperatures to be further away from the occupants. Today, in houses covered by cement or fibre cement, we can clearly feel the difference in temperature as one approaches the low ceiling. The introduction of ventilation openings (LO and HO) helps to minimize the heat near the ceiling and favours the indoor cooling, as can be seen on iso-surfaces (Table 3).

Table 3. Results presented in terms of iso-surfaces at 12 p.m.: a) WO, b) LO, c) HO and d) MO.

	(a) WO	(b) LO	(c) HO	(d) MO	**Scale**
CR1					Air Temperature - °C 

The lines on the iso-surfaces, in the space without openings, show that the indoor space presents high temperatures. The introduction of ventilation, in the three forms proposed, reduces the temperature at the occupant's level.

Table 4. Results presented in terms of air temperature at 4 p.m.: a) WO, b) LO, c) HO and d) MO.

	(a) WO	(b) LO	(c) HO	(d) MO	**Scale**
CR1					Air Temperature °C
CR2					
FCR1					
FCR2					

The results in CR1 and CR2 show the effect of the light-coloured paint in minimizing the absorption of heat and therefore its transference to the room. In addition, the use of ventilation makes an important contribution to promoting even greater cooling indoors.

The results in FCR1 reach high levels of thermal stress, which can be observed in practice. The presence of light-coloured paint in FCR2 indicates a reduction of indoor temperature, as well as of the area close to the ceiling.

The introduction of openings, even small ones, in low and high positions, is able to promote an increase in ventilation in a passive way. The introduction of cross-ventilation in small spaces can help us in project decisions. This strategy is particularly useful when dealing with the lack of space around the buildings in hot-climate regions.

Conclusions

The simulation results were able:

- to give expected results for the heat transfer on flat roof take into account materials;
- to show the interference of the locations of the openings on ventilation consequently on the air temperature;
- to change the variation of the global intensity of incident solar radiation (Ig) during the simulation process according to the day hour (hourly from 7am. to 5pm).

The possibility to deal with the variation of solar radiation during the simulation is a way to have results closer to what is observed in loco, as each step in the simulation takes into account the previous one.

In all the experiments, the expected changes in the ventilation and temperature fields were observed, which might indicate that the subroutines used were indeed able to show the dynamics of temperature and ventilation.

The following stage of this study will deal with the changes of wind direction during the simulation process.

Acknowledgement

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CFD for Reliable Wind-Driven Natural Ventilation Studies in the Built-Environment; the Process Demystified

Bakr Gomaa[1]

[1] Architectural Engineering and Environmental Design Department, Arab Academy for Science, Technology, and Maritime Transport, Alexandria, Egypt. b.gomaa@aast.edu

Abstract: Natural ventilation in the built environment is a promising field with great potential in improving IEQ, as well as indoor and outdoor thermal comfort. For a long time, CFD has been used as an invaluable tool for exploring the mutual impact between the built-environment and air flow. On the other hand, uncertainties of the tool such as the impact of mesh quality, turbulence models, velocity profiles, and convergence criteria on the accuracy of results cloud its precision. A number of articles have discussed such problems, and in the process, they have profiled the constraints that mark the criteria of a reliable computer simulation. While such constraints establish the scientific rigor required; they add to the complexity of CFD and may cause hindrance to research development. This paper reviews previous research to demystify the process of running a scientifically reliable CFD simulations especially for wind-driven ventilation in the built-environment. To do this, we explore the literature and through a case study simulation of a box building each step is investigated and results are used to define the cross-ventilation potential across the corners of the box.

Keywords: Wind driven, Natural Ventilation, CFD, Process, Cross Ventilation

Introduction

Ventilation in buildings is the process of creating certain conditions for cooling, and/or enhanced air quality. Minimum air replacement rates can aid remove internal heat gains, and indoor pollutants (Irving et al., 2014). While ventilation can be mechanical, natural ventilation is the green alternative, that can utilize wind (pressure difference), and/or buoyancy (conductive) to drive air movement (Irving et al., 2014).

Computational Fluid Dynamics (CFD) software is one way of investigating air flow in and around buildings. The software conducts numerical analysis for the problem defined by the user. Their results are then heavily dependent on users' accuracy, rigor and understanding of the problem. This is understandably a place of great concern for scientific value of CFD use especially in scientific advancement.

Many articles have discussed simulation guidelines and tips, and in many cases the entire process is neglected. It is then our objective to define the correct procedure of a scientifically accurate CFD simulation. To do this, literature is explored to formulate the phases of a CFD simulation, and the different variables required. The paper concludes in a case study application in which CFD simulation is used to identify the cross-ventilation potential across the corners of a box building.

CFD: The Process

A CFD simulation process comprises of six main phases; definition of simulation variables(s), identification of the problem characteristics, model and mesh design, simulation, validation and finally results analysis. Figure 1

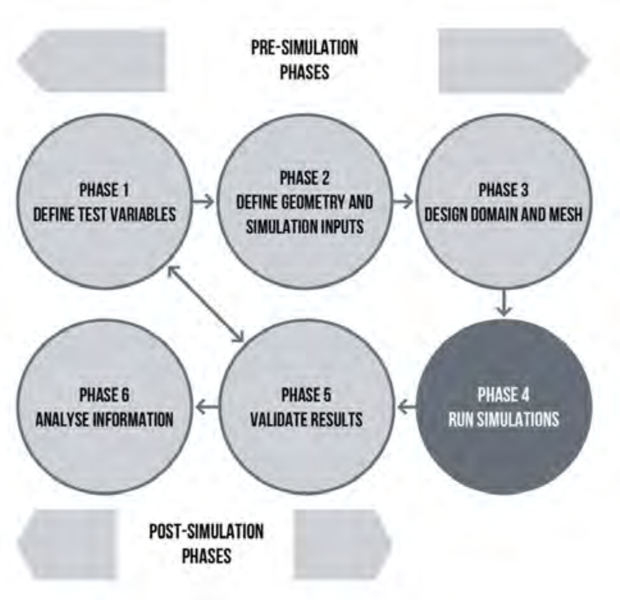

Figure 1. Phases of a CFD simulation

Phase 5 of the process -validation of results- also initiates the study as it defines the first two phases of the process. According to (Oberkampf and Trucano, 2002) validation is the comparison of simulation results against results from other sources to ensure accuracy. It is then important that CFD results are comparable to either real life measurements or wind tunnel test (Lirola et al., 2017). Successful validation/comparison of CFD results to experimental work then requires the use of nearly similar characteristics across the test and the simulation (e.g., building geometry).

Based on the first two phases of the study; the user can then design the suitable domain and mesh. The domain is the volume that surrounds the model, while the mesh is the subdivision of the model and domain into a number of small volumes. Both define the extent in which the computer would later conduct the numerical calculations (2006).

Simulation run is the fourth phase in which the machine actually conducts the numerical calculations. Such phase should terminate into 'convergence' where the final results reach a satisfactory level of accuracy. Convergence also involves mesh independence test, in which the user ensures that the results do not change drastically with finer mesh (Roache, 1994). Post simulation the designer can validate results and conduct required analysis of information for their required purpose.

Simulation Variables

Any simulation is a representation of the fluid behaviour in or around specific boundaries governed by laws of mechanics (White, 2011). For this, in addition to the geometric characteristics of the simulated case, the CFD software user should aim to identify three important variables from the tested case; its Reynolds number (Re), vertical velocity profile, and turbulence variables.

According to (White, 2011); Re is a figure that describes the relationship between the fluid's inertial and viscose forces. It is a representation of whether the flow is turbulent or laminar, and then can be used to ensure that scaling factors between tests and simulations do not change the flow characteristics.

Air velocity is understandably a critical factor in wind driven ventilation, and is one of the main inputs of a simulation. For this input air velocity must be identified especially if it has specific vertical profile, which is very common in natural ventilation studies. It is the impact of earth's surface friction on wind velocity, and its shape will depend mainly on the urban form, its density and organization (Wieringa, 1992).

On the other hand, turbulence variables are turbulence model, turbulence quantities and vertical profile(s). A CFD software has to resolve a number of equations, such as momentum and continuity, and turbulence models are one way to simplify such equations. According to (2006), a CFD software can use one of two groups of turbulence models; Reynolds Averaged Navier-Stokes (RANS) models and Large Eddy Simulation (LES) models. The same source admits that no turbulence model is universally accepted, because each model has its benefits and drawbacks.

Different turbulence models require that the simulation designer identifies specific values for turbulence quantities. For example, the RANS Standard k-ϵ model requires user inputs for the turbulent kinetic energy (TKE), and turbulence dissipation rate (ϵ). In addition to this, it is also important to identify whether such values are variable with height, which is mainly dependent on the velocity profile discussed before.

Domain and Mesh

The domain is a volume that defines the outer limits of the computational efforts around the simulated case. It has a number of boundaries that should not interfere with the fluid flow while at the same time provide correct resemblance of the simulated environment (Ramponi and Blocken, 2012).

A 3D domain is sized in relation to the dimensions of simulated case. The cross section is sized based on the blockage of the simulated building, while the length includes the upwind region, the building(s) length, and the downwind region. Two main theories can be identified in that matter; one states that the domain edges should be a minimum of 5H (H being the maximum height of the simulated case) away from the top and sides of the model (Oliveira and Younis, 2000). Another theory showed concern about 'wide' building models that may cause severe blockage when sizing the domain width based on model height only (Blocken, 2015). The same reference recommended that a maximum of 17% blockage ratio between the domain and model width should dictate the domain cross section. For the length of the domain, both theories agree that the upwind distance can be 5H while downwind distance is 15H.

Besides sizing the domain, it is also critical to identify the nature of its boundaries for the simulation physics to be resolved correctly. Input boundaries are used as air flow source, and at which the user identifies the velocity profile, along with the turbulence model terms and profiles. Output boundaries on the other hand are critical for the calculation of flow exiting the domain. Wall boundaries are used to simulate reasonable roughness especially at the bottom of the domain (where the ground landscape is simulated). Unfortunately, common commercial CFD software is currently unable to simulate large roughness implicitly. Further studies on this can be found in (Blocken et al., 2007). Also symmetry boundaries are used when the simulation geometry and flow are symmetrical along one of the domain axis (2006).

Meshing on the other hand defines the resolution and quality of the small units in which the machine resolves that problem (2006). Resolution is a measure of cells density in critical regions of the simulation, and quality is a matter of cells shape and proportions. Both factors can be controlled by a technique devised in (Van Hooff and Blocken, 2010) in which the mesh is created in 2D planes and converted to 3D using a number of extrusions.

Simulation Phase

In the simulation phase, the machine runs the numerical calculations to reach convergence. The CFD solver simultaneously solves governing equations in each mesh cell in the domain and updates the different properties of fluid flow. While CFD can iterate this process for as long as the user requires, (FRANKE et al., 2010) recommended two targets to judge convergence; 1. Residuals of momentum, continuity, TKE, and supplementing turbulence variable (e.g. ϵ) drop by no less than 6, 4, 5, 4 orders of magnitude respectively. 2. User should monitor an important variable of the simulation (e.g. velocity in critical location) to ensure that it is stable and not changing with more iterations.

The CFD software then conducts 'Spatial Discretization' in which the results calculated in the cell centers are interpolated to cell face(s). Such process can be done to various accuracies based on users choice. (FRANKE et al., 2010) and others suggest that Second-Order Upwind discretization scheme is used for scientific rigor.

Another equally important factor of a successful simulation is mesh independence test. While this part of the process is related to meshing it is in fact more relevant to convergence. In the mesh independence test; the user must refine the mesh, and repeat the simulation at least three times. This is to ensure that results are not dependent on mesh resolution. Also Grid Convergence Index (GCI) devised by (Roache, 1994) provides a measure to assess the impact of mesh refinement on final results. Figure 2

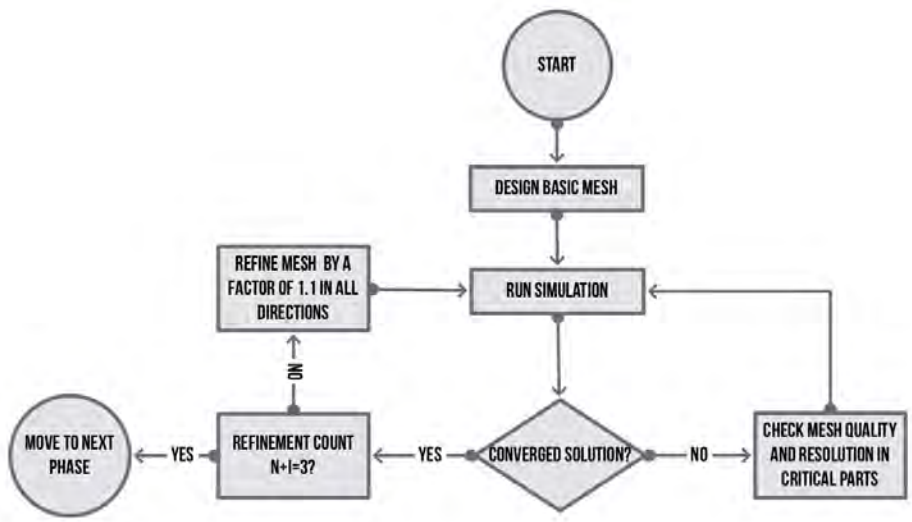

Figure 2. Flow chart showing the process of mesh independence testing

Case Study: Cross Ventilation Potential Across a Box Building

Cross ventilation in buildings is the process by which fresh air flows between two windows on opposite or adjacent walls, and is highly dependent on the pressure differential across the two openings. Cross ventilation in buildings is usually estimated using opposite windows configuration, thus it is common that ΔCp (pressure coefficient differential) between the windward and the leeward walls at central height (Irving et al., 2014) is used to define air flow due to cross ventilation. We argue that cross ventilation at the corners of buildings at different heights requires more attention and can clarify design factors that may enhance buildings design for natural ventilation (e.g., the variability of windows areas to suit the intensity of the pressure differential). Many studies such as (Ramponi and Blocken, 2012) and (Li et al., 2015) have investigated pressure coefficient patterns on simple building shapes and different settings for the general understanding of air flow, pollutants dispersion or structural loading. To the best of our knowledge, none however has defined the term CVP, nor used it to investigate the pressure differential on the buildings corners. We define CVP as the possibility of achieving specific cross ventilation conditions (Gomaa, 2016). The target of the study is then to utilise previously mentioned phases of an accurate CFD simulation on a simple box building that can then be used to identify the cross-ventilation potential across the box corners at the heights 1/3 and 2/3H.

Test and Simulation Inputs

The study is to be validated against the wind tunnel tests held in Tokyo Polytechnic University (Japan) and discussed in (Kim et al., 2012). The experimental test investigated the sheltering effect of different urban configurations compared to a standalone building. According to (Kim et al., 2012) the experiment had a Reynolds Number of 50,000 and vertical velocity profile with a log exponent of 0.2. Wind speed and turbulence intensity at building height were 7.2 m/s and 23%. For the simulation, we used Shear-stress transport (SST) k-ω model in which average speed and turbulence intensity profiles of the test were used to define the terms TKE and ω. Figure 3

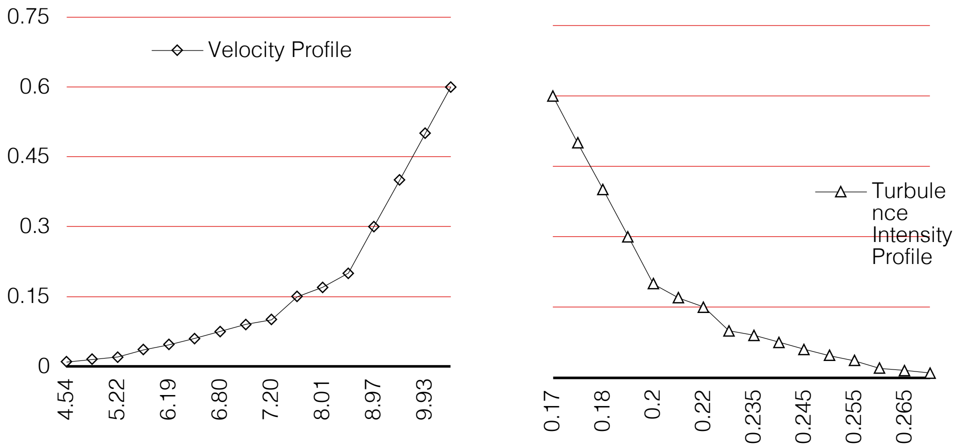

Figure 3. Velocity (left) and turbulence intensity (right) profiles used at inlet boundary of the CFD simulation after (Kim et al., 2012)

Domain and Mesh Design

Due to the small size of the case; domain sizing followed the theory of (Oliveira and Younis, 2000), however, the windward region of the domain was designed to be only 3H as indicated in (Blocken, 2015). This is to reduce the anticipated changes to the velocity and turbulence profiles due to small values of the implicit friction at the bottom of the domain. Also, only half the box building was modelled due to its symmetrical nature. Symmetry boundaries were used for the splitting edge and the side of the domain. Velocity inlet boundary was used at the inlet, pressure outlet was used at the domain end, and wall boundaries were used for the top and the bottom sides. The top of the domain however was simulated with zero friction, while the bottom had wall roughness of height of 0.0075 and roughness constant of 7. Such values had been calculated to simulate a smooth terrain (Z_0 height of 0.005) as indicated in (Wieringa, 1992).

Structured mesh was used by planning the mesh concentrations on the plan view of the domain and the edges of the box, which was then extruded twice; first to extrude mesh to building height, second extrude domain and building again to domain top. This process formed a 194,955 cells 3D mesh model. Figure 4

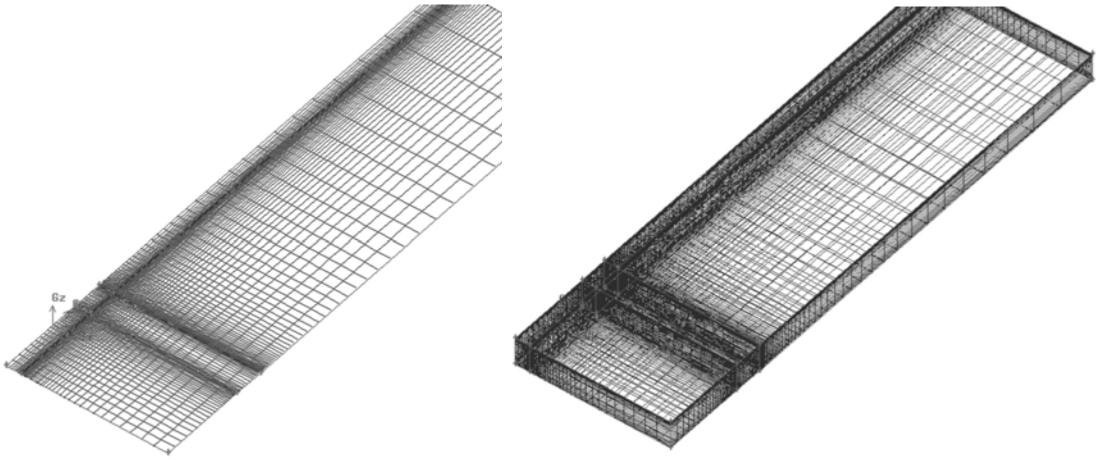

Figure 4. Left: mesh planning on the 2D level helps control grid concentrations in critical parts of the model. Right: image showing one step of the mesh extrusion in the 3rd dimension (to building height)

Simulation

The simulation was conducted using the solver Fluent 6.3; in which Pressure-Velocity coupling through SIMPLE algorithm and Second-order discretization scheme for all governing equations were utilized.

Mesh independent results were verified by coarsening initial mesh twice each at a factor of 1.1 in all directions. Roache index for the vertical pressure coefficient showed that the average discrepancy between the coarse and medium grids is 10.2% with standard deviation of 19.4. The index for the medium and fine grids on the other hand is 4.3% with standard deviation of 6.8. The largest error was for the windward edge right before the roof in which the error was 106.6 and 28.5 between the coarse-medium grids and the medium-fine grids respectively.

The comparison of the pressure coefficients across the vertical centre line of the box to test results showed a general good agreement, and excellent match at the windward side of the box. The discrepancy however was more pronounced in the separation zone at the windward edge of the roof and the back of the box. This is believed to be due to CFD uncertainties especially related to the effect of the different turbulence models. Figure 5

Cross Ventilation Potential

To define the CVP, we compared the pressure coefficient differential (ΔCp) across the corners of the building to a reference value (ΔCp_{ref}). ΔCp is calculated by subtracting the Cp values across the front and back corners at the heights 1/3H and 2/3H. Horizontally corner points lie

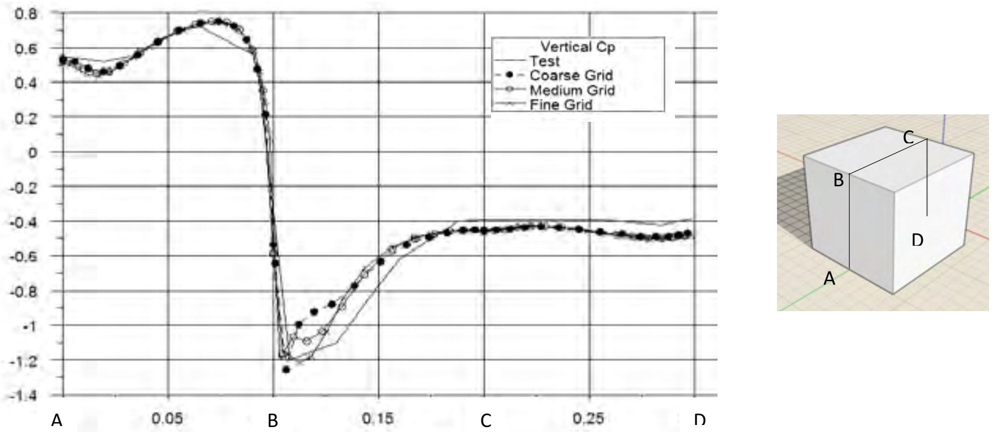

Figure 5. Vertical pressure coefficients along the centre line. Comparison between the results of different grids, and experimental test

at 1/3 building width on the windward and leeward facades, and at 1/3 and 2/3W on the side facade. Also, ΔCp_{ref} is calculated by subtracting Cp values between the front-back walls of the same building at 1/2H. Figure 6

While ΔCp_{ref} was calculated to be 1.14, ΔCp was found to be 1.45, 1.7, -0.1, and -0.07 for the top front corner, lower front corner, top back corner and lower back corner respectively. This shows that CVP is highest at the top front corner at 1.49, followed by the lower front corner at 1.27. The back corners showed very poor CVP with the values 0.088 and 0.061 for the top and lower corners respectively. Figures 6 and 7

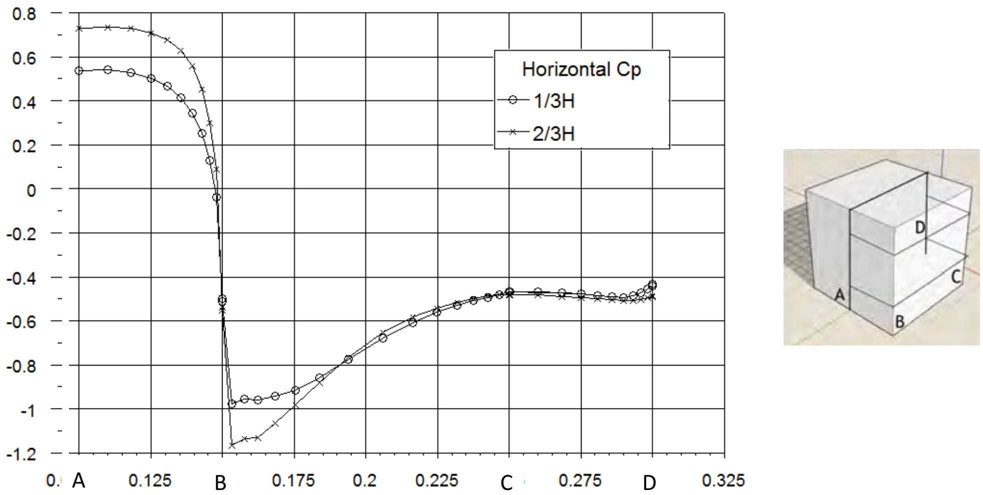

Figure 6. Horizontal pressure coefficients at the heights 1/3 and 2/3H

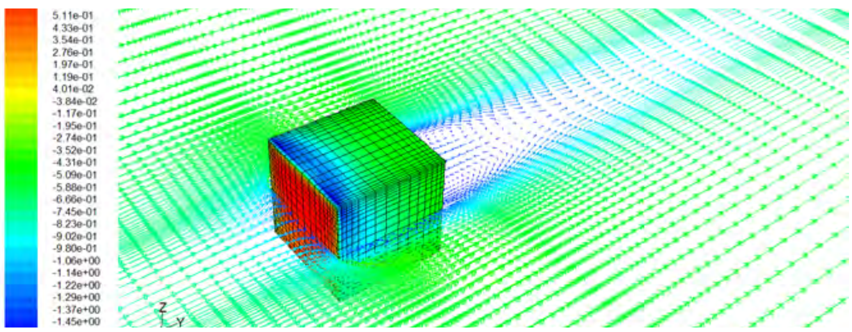

Figure 7. Pressure coefficient patterns and air flow around the box

Conclusion

This paper provides a clear path for an accurate CFD simulation. A CFD study should be supported by an experimental investigation, which defines the simulation variables. On the model level, the domain sizing must produce minimal blockage, while the mesh should be conducted with maximum control over cells concentration and quality. Also results should be checked for grid independence. For the simulation; high order discretization scheme should be used and final results compared to measurements. Based on this a case study was conducted to compare the cross-ventilation potential (CVP) between the different facades of a box building. The simulation showed that compared to CVP between the windward and leeward facades of the buildings; windward and side walls achieved higher CVP by at least 27%, while side walls and the leeward wall had lower CVP by no less than 91%.

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Influence of application of accurate airflow resistance on openings with different configurations of shading devices on the building thermal performance

Liliane Maciel[1], Matheus Oliveira[2], Sabrina Barbosa[2], Joyce Carlo[2], Álvaro Tibiriçá[3]

[1] Graduate Architecture and Urban Planning Program, Federal University of Viçosa, Viçosa, Brazil, Educational Institute Santo Agostinho, Montes Claros, Brazil, lilianefmaciel@gmail.com
[2]Graduate Architecture and Urban Planning Program, Federal University of Viçosa, Viçosa, Brazil, matheus.meneses@gmail.com, s.andradebarbosa@gmail.com, correnacarlo@gmail.com
[3] Department of Production and Mechanical Engineering, Federal University of Viçosa, Viçosa, Brazil, alvaro.tibirica@gmail.com

Abstract: With large cooling potentials, natural ventilation is the main passive technique applied to tropical buildings. In computational simulations studies, the discharge coefficient (Cd) is required as a parameter to characterize the resistance the opening imposes to the airflow. As shape and angle of shading devices influence the airflow through the openings, accurate setting of Cd has a significant impact on the characterization of the cooling phenomena. This study investigates the effect of accurate Cd of five different configurations of shading devices. Using a classroom as a generic case, corrected Cd obtained from CFD models were used to simulations on the software EnergyPlus identifying airflow levels and periods of thermal comfort under the climate conditions of São Paulo. Results indicate that using 0.6 as a Cd value in the simulations is adequate for openings with shading devices that has a lower level of obstruction on the façade. However, for geometries with several slats and low angles, Cd values can be as low as 0.34. In this case, the airflow through the room decreases in average 15% in relation to the model that used usual Cd. The outcomes contribute to a more precise prediction of natural ventilation of buildings with shaded openings.

Keywords: Natural ventilation, Discharge coefficient, Shading devices, Computational fluid dynamics

Introduction

Natural ventilation is the main passive technique applied to tropical buildings compared to other design strategies. With large cooling potentials, the control of air movement through the internal environment can improve thermal comfort and indoor air quality with reduced operating costs. Building layout, size and location of apertures are relevant architectural variables to produce effective natural ventilation (Aflaki et al., 2015).

In studies on the natural ventilation in buildings, careful characterization of obstacles to the flow on the envelop, such as shading devices, is necessary to avoid inadequate assessment that can lead to large deviations between the computational predictions and the real ventilation conditions (Cruz and Viegas, 2016). The resistance the opening imposes to airflow, i.e. the quantification of the efficiency of airflow through an opening is given by the discharge coefficient (Cd). Accurate specification of Cd has a significant impact on the model capacity to describe cooling and ventilation phenomena. However, in buildings thermal performance research, some computational dynamic thermal simulation software, such as EDSL-TAS, EnergyPlus and ESP-r assume that Cd depends merely on the opening geometry (Cóstola et al., 2009), assuming generalized values.

As shape, position and angle of shading devices influence the airflow through the openings, accurate setting of Cd may have a significant impact on the software capacity in describing cooling and air changes effects of the natural ventilation. In order to investigate the effect of application of flow resistance on openings with different shading devices types and angles, this study determines accurate Cd of five different configurations of shading devices through Computational Fluid Dynamics (CFD). Using a classroom as a generic case, corrected Cd obtained from CFD models were used to simulations on the software EnergyPlus identifying airflow levels and periods of thermal comfort under the climate conditions of São Paulo city, Brazil.

Effect of the discharge coefficient on the ventilation performance

Cd is a dimensionless number that depends on the opening geometry and on the Reynolds number of the flow (Ashrae, 2013). It ranges from 0 to 1 to represent a fraction of energy to the ventilation. If Cd is close to 0, it means that the opening imposes a major loss on the energy of the airflow, while if it tends to 1, the energy loss is low. The loss is caused by friction, turbulence and it is related to air viscosity, thus, varying according to the opening´s shape and position regarding the airflow incidence and the flow path, i.e. if the air is entering or leaving the building (Cóstola et al., 2009).

Users face difficulties to accurately specify the Cd value as data available in the literature present variations. Analysing the influence of architectural parameters on the thermal performance of simulations of naturally ventilated buildings, Sorgato and Lamberts (2012) identified that Cd values vary up to 91%, which can compromise the results reliability. For instance, if Cd is estimated to be 0.6 when its real value is 0.3, the effect is the same of using an opening area of 2.00 m² when the real area is 1.00 m² (Cóstola et al., 2009).

For unidirectional non-turbulent flow caused by chimney effect, Ashrae (2013) recommends a Cd value of 0.65 and for sharp edge openings, 0.6 is the value indicated. Hult et al. (2012) recommend 0.61 as a Cd value for sharp edge rectangular openings. Tecle et al. (2013) achieved Cd values ranging from 0.65 to 1 for low-rise buildings and identified that Cd is highly dependent on the opening area and on the window to wall ratio.

When the opening has shading devices, the difficulty in defining the Cd value is even greater due to the lack of information about the diversity of shapes and sizes the shading devices can assume. There is still little information available about the effects of external shading devices for solar control on the airflow perturbation, which turns difficult the characterization of the openings and, hence, the performance evaluation of natural ventilation in buildings.

Methodology

Models description

The model used comprises of a rectangular model based on an educational building with the longest sides oriented to South/North. A classroom in the middle of the building was chosen for this study, which dimensions of 6m x 10m and 3.5m floor-to-floor height. The room presents a window opening of 20.5 m^2, positioned on the North wall (Figure 1).

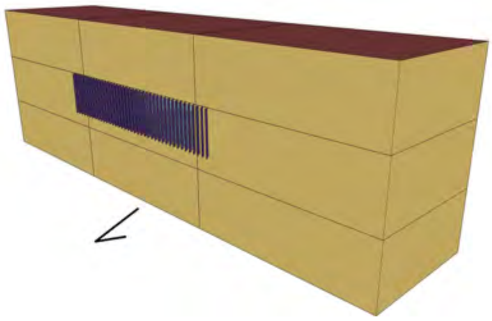

Figure 1. Building model used on the simulations

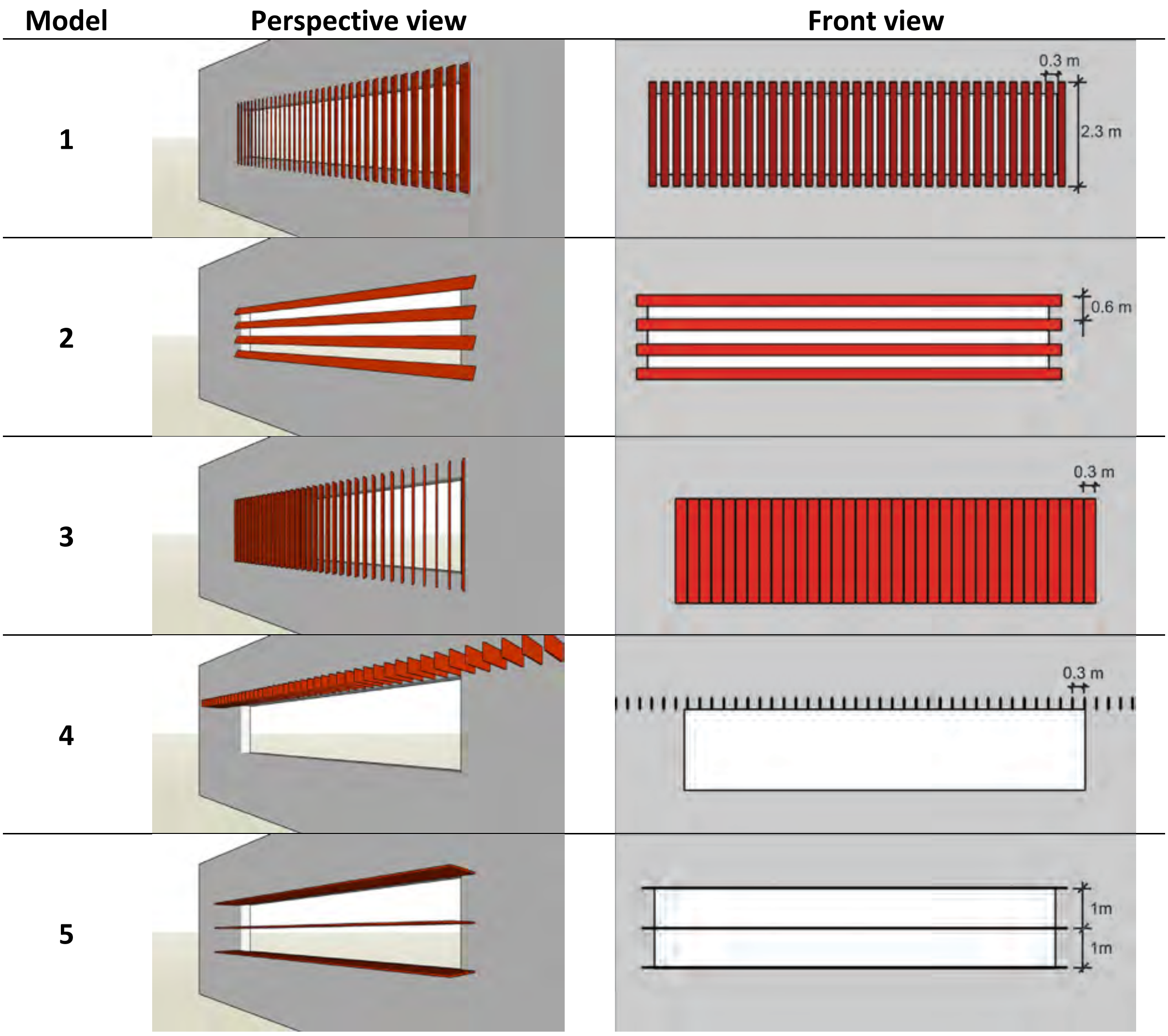

Figure 2. Shading device configurations tested

The shading devices configurations tested were obtained from a database with 30 types of brise-soleis presented by Lamberts et al. (2014), which dimensions can be modified resulting in an endless number of possibilities. Five usual shading devices were selected, as shown in Figure 2, for which the discharge coefficients were determined through CFD simulation. The values of Cd obtained in this paper were determined for unidirectional fluid flow, from exterior to the building interior.

CFD simulations

The discharge coefficients of the models tested were obtained from the CFD commercial package Ansys CFX® (version 15.0). In the CFD technique, the external atmosphere and the air space in the interior of the building are divided into domain geometries. Solid boundary layers, such as walls, ceilings, windows, are then defined and a mesh of small cells is included in the spaces, creating a grid. From that, basic fluid dynamics equations for conservation of mass, momentum and thermal energy are solved for all nodes of the grid, giving a detailed picture of the flow pattern (temperature, air velocities and pollutant distribution) in the room.

To verify consistency of the results to provide confidence in the CFD results, the models were verified based on the method used by Yang et al. (2010) in which the discharge coefficient of a window with differing degrees of opening were compared using both wind tunnel testing and CFD simulation. Yang et al. (2010) have tested opening angles of 10°, 30°, 45°, 60° and 90°, which were reproduced in the present study. The test indicated close agreement to those achieved by Yang et al (2010). To increase confidence in the results, a grid dependence test was performed through successively enhancement of the total number of elements until the Cd value did not change more than 1%.

Using steady state condition solutions, the models were set with the Shear Stress Transport turbulence model as it combines k-omega, used in the inner region of the boundary layer and the k-epsilon, specifically for planar shear layers and recirculating flows. The grid was generated by Ansys Meshing with tetrahedral elements and local refinement near to the opening and shading device was considered.

Thermal dynamic simulations

Cases with different configurations of shading devices were modelled and simulated on the EnergyPlus software. All cases were simulated under the climatic conditions of São Paulo. The weather data used is based on the test reference year (TRY) database used by the Brazilian Energy Efficiency Labelling (Inmetro, 2010). As the climatic conditions of São Paulo is characterized by mild and low temperatures, especially in the winter, the window openings control were set according to outside temperature. The opening regulator was set to start to open the North window when the outside temperature is above 16°C and modulates the degree of opening linearly until it is fully open at 20°C. The properties of the materials used on the building models and the internal heat gains profiles are specified in
Table 1.

Table 1. Characteristics of the model

Construction materials	
Ceilings	3.73 W/m^2K
Walls	1.74 W/m^2K
Use of the building	**Total gain**
Internal heat gains (People + Equipment + Lighting)	138 W/m^2

Results of thermal comfort levels are based on the standard ASHARE-55 (2013), which uses the adaptive approach to consider the indoor acceptable temperature as a function of the outdoor air temperature. With a more realistic comfort range of operative temperatures, it provides a suitable method for predicting the thermal acceptance levels of naturally ventilated buildings under tropical climate conditions.

Results and discussion

Discharge coefficients obtained from CFD simulations

Table 2 shows Cd values obtained for the different shading devices applied to the model. Results indicate that shading devices can act as a blockage to the airflow or enhance the natural ventilation depending on its configuration on the façade. Therefore, the use of a generic Cd for facades with different shading device configurations should be avoided. The lack of accurate Cd specifications may compromise the reliability of the results on the thermal performance of naturally ventilated buildings.

Table 2. Shading devices' discharge coefficients

Shading device	Discharge Coefficient
01	0.34
02	0.41
03	0.57
04	0.65
05	0.65

Cases with low angle shading devices presented the lowest Cd for both vertical and horizontal slats. For the case with slats angled 60°, the resulted Cd was slightly lower than the value commonly used, 0.6. On the other hand, cases 4 and 5, which have shading devices above the window opening and orthogonally horizontal in front of the window, respectively, resulted in similar Cd, with a value of 0.65. This indicates that the Cd value frequently used in simulation software is adequate for shading devices that has a lower level of obstruction on the façade. However, for shading geometries that works as a barrier to the flow, corrected Cd should be considered for accurate results.

Models thermal performance

Table 3 presents the daily average incident solar radiation reaching the outside North window surface. It represents the radiation incident on the window after passing through the shading devices, in each case. As expected, case 4 presented the highest level of solar radiation reaching the window as the shading device has a low level of obstruction, especially during the winter and close to midday. However, considering the high internal heat gains and the risk of glare, solar incidence is not welcome in this case. On the other hand, in case 2, the solar radiation reaching the window was 4 times lower than case 4. This is due to the suitable shading device configuration applied. Although some shading devices geometries tested are not appropriate to the room orientation, having, therefore, a great influence on the thermal comfort of the building model, this study focus on the differences in the thermal performance when corrected and usual Cds are used.

Table 3. Mean incident radiation and airflow net airflow through the window

Model	**1**	**2**	**3**	**4**	**5**
Cd	0.34	0.41	0.57	0.65	0.65
Incident radiation	113 W/m^2	42 W/m^2	96 W/m^2	168 W/m^2	90 W/m^2
Airflow	0.32 m^3/s	0.33 m^3/s	0.38 m^3/s	0.41 m^3/s	0.38 m^3/s

Table 3 also includes the annual mean of the net airflow through the window opening of the models simulated. The greatest air movement was observed on case 4, which has the lower obstructive shading device amongst the models tested. On the other hand, case 1 presented the lower airflow, as the vertical shading device with a low angle prevented the air from entering the room. In this case, the differences of airflow through the room was in average 15% between the models that used corrected and usual Cd.

Monthly totals in terms of comfortable and uncomfortable occupied hours (both due to too hot/too cold conditions) are presented for case 1, which presented the lowest correct Cd among the cases tested (Figure 3). In this case, results indicate thermal discomfort due to too hot conditions occurring in 12% of the daylight hours, being January to March the hottest periods of the year, when discomfort can reach up to 36% of the month. The model with usual Cd (0.6) applied to the window opening, resulted in 3% lower levels of too hot conditions, corresponding to 118 hours (Figure 4). The high internal gains due to the great number of people in the room and the relatively high levels of solar radiation reaching the opening can explain the moderate effect that ventilation has on the thermal comfort when comparing cases using corrected and usual Cd.

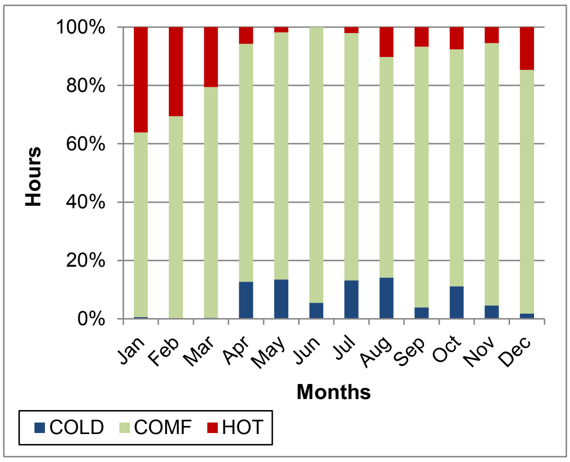

Figure 3. Hourly thermal acceptance of model 1 with corrected Cd (0.34)

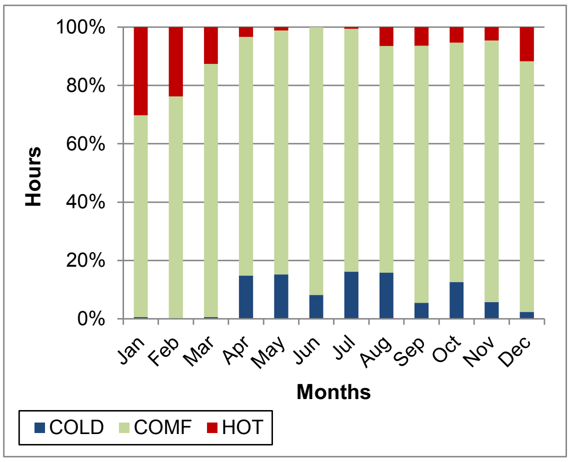

Figure 4. Hourly thermal acceptance of model 1 with current used Cd (0.6)

The lowest levels of discomfort due to overheating was observed in case 5, in which horizontal slats were applied to the window. This is explained by the adequate configuration of the shading device shape applied according the window orientation, which effectively worked as a barrier to the solar radiation, limiting solar heat gains into the room. Additionally, the greatest airflow allowed through the window also contributed to enhance the thermal comfort in the classroom. On the other hand, Case 2 resulted in the highest levels of discomfort due too cold conditions, as several horizontal shading devices was applied to the model, which limited solar gains into the room. Table 4 summarizes the thermal acceptance results for all cases tested.

Table 4. Summary of thermal acceptance conditions of cases 1 to 5

	Model 1		**Model 2**		**Model 3**		**Model 4**		**Model 5**	
	Cd = 0.34	Cd = 0.6	Cd = 0.41	Cd = 0.6	Cd = 0.57	Cd = 0.6	Cd = 0.65	Cd = 0.6	Cd = 0.65	Cd = 0.6
LOW	7%	8%	11%	12%	7%	7%	5%	5%	9%	9%
CONF	81%	83%	81%	81%	84%	84%	84%	83%	83%	83%
HIGH	12%	9%	8%	6%	9%	9%	11%	12%	7%	8%

Conclusions

The outcomes from this research contributes to a more precise prediction of the thermal performance and air quality of naturally ventilated buildings with shaded openings under tropical climate conditions providing basic guidance to designers at the conceptual design stage. In the view of the importance and lack of information of accurate characterization of the resistance the different shading devices configurations imposes to airflow, this study determines accurate discharge coefficients of five different configurations of shading devices through Computational Fluid Dynamics (CFD). Using a classroom as a generic case, corrected Cd obtained from CFD models were set to simulations on the software EnergyPlus identifying airflow levels and periods of thermal comfort under the climate conditions of São Paulo city. Models with similar characteristics but with currently used fixed Cd were also simulated for comparison.

Results indicate that the use of 0.6 as a general Cd value in simulation software is adequate for openings with shading devices that has a lower level of obstruction on the façade. However, for shading geometries with several slats and low angles, covering the opening, values as low as 0.34 were identified and corrected Cd should be considered for accurate results, as it imposes a resistance to the airflow. The greatest airflow levels were observed for the case which shading device was applied on the top of the window, which has the lowest obstructive elements amongst the models tested. The Cd value obtained in this case was similar to the usual value used (0.6). On the other hand, the model with several vertical slats angled 60° presented the lower airflow, as the shading device prevented the air from entering the room. In this case, the differences of airflow through the room was in average 15% between the models that used corrected and usual Cd.

It is important to notice that the Cd values were obtained from a CFD simulation set with a constant value for wind speed and direction. Thus, different wind conditions and shading devices configurations could be further studied in parallel with wind tunnel experimental measurements to enhance the credibility of the results from computer simulation.

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Ventilation performance and end-user interaction: Comparison of natural and mechanical strategies in new-build social housing

Gráinne McGill[1*] and Tim Sharpe[1]

[1] Mackintosh Environmental Architecture Research Unit, Mackintosh School of Architecture, Glasgow School of Art, Glasgow, Scotland. Corresponding email: g.mcgill@gsa.ac.uk

Abstract: Adequate ventilation is critical to ensure effective removal of moisture, air pollutants and smells indoors. A growing body of evidence however suggests poor performance of ventilation strategies in modern housing, which raises concerns regarding the potential detrimental impact on indoor air quality. The risk of health effects resulting from exposure to indoor air pollutants is exacerbated by the reduction of natural infiltration rates brought about by improvements to the fabric performance of buildings. Whilst these improvements should help to reduce energy consumption and occupant discomfort due to draughts, there is a need to ensure ventilation does not deteriorate as a result. To ensure effective ventilation provision in modern social housing, it is important to understand and evaluate how these different strategies perform in a real-life context. This paper presents the results of a post-occupancy evaluation of three new-build social housing developments in Glasgow, ventilated by natural, mechanical extract and mechanical heat recovery methods. The study included household surveys of the three developments (responses from 63 households) and detailed monitoring of eight dwellings, to include occupant interviews, indoor environmental monitoring (during various seasons), fabric performance testing (airtightness, u-value assessment and thermography survey), energy monitoring, ventilation testing and indoor air quality measurements. The results provide interesting insights regarding how occupants engage and interact with the ventilation strategies, the performance of ventilation strategies in practice, and occupant awareness and understanding of ventilation. The findings indicate shortcomings in all evaluated ventilation methods.

Keywords: Ventilation, Social Housing, Energy-efficiency, Building Users

Introduction

Ventilation is the continual exchange of contaminated air with fresh air in a building. Ventilation is critical to dilute indoor pollutant concentrations to acceptable levels for occupant health and comfort. It is also necessary to remove moisture and smells indoors, to provide sufficient oxygen supply for building occupants and for the provision of direct and indirect comfort cooling or heating (Roaf and McGill, 2016). Ventilation is a fundamental determinant of indoor air quality in buildings. However, ventilation alone cannot ensure adequate indoor air quality (Borsboom et al., 2016).

Numerous scientific reviews have established biological plausibility for an association between ventilation rates in buildings and health outcomes (Wargocki, 2013). However the development of health-based ventilation standards have been impeded by the limited epidemiological evidence and inconsistencies regarding the way in which buildings, exposures, pollutant sources and outdoor air quality are characterised (Bischof et al., 2013). Whole house ventilation rates of at least 0.5 ach are recommended to reduce house dust mite infestation and associated allergic manifestations (Bornehag et al, 2005).

As heat loss through the building fabric decreases with improved thermal insulation, heat loss associated with ventilation (purpose provided and adventitious) becomes more substantial. The UK domestic sector has seen significant improvements in airtightness standards over the last two decades. Whilst these improvements should help reduce energy consumption and occupant discomfort due to draughts, there is a need to ensure ventilation does not deteriorate as a result.

The overall impact of improvements to fabric performance on whole house ventilation provision and indoor air quality (IAQ) in new-build UK housing has yet to be effectively determined. While emerging studies have highlighted concerns regarding the effectiveness of ventilation systems, robustness of systems in practice and end-user interactions (Howieson et al., 2013; Sullivan et al., 2013), a greater understanding of the problem is required, to increase awareness of potential performance gaps and to provide practical advice to architects and construction professionals.

To ensure sufficient ventilation provision in modern new-build social housing, it is important to understand and evaluate how various ventilation strategies perform in a real-life context. This study therefore aims to gather evidence of how passive stack, Mechanical Ventilation with Heat Recovery (MVHR) and decentralised Mechanical Extract Ventilation (dMEV) perform in a real-life social housing context, to establish an in-depth understanding of the possible causes of performance gaps and the potential implications of these. In addition, it aims to gain a deeper understanding of the importance of end-user interaction on ventilation performance.

Methodology

An initial large scale door-to-door survey was undertaken at the three sites using a short questionnaire to gain information on occupant behaviour, perception of indoor environmental quality and awareness and use of ventilation in the home. Information was gained from 63 households (response rate: 74%). Eight households were selected for detailed monitoring (Table 1), based on representativeness, availability and concerns expressed regarding environmental performance.

Detailed monitoring consisted of the following: i) Indoor environmental monitoring (Eltek IAQ data loggers), ii) Occupant interviews, iii) Airtightness testing, iv) U-value assessment (Eltek SG44 HB transmitter), v) Thermography survey (FLIR thermacam B360), vi) Sound measurements (Pulsar Real Time Analyzer), vii) Ventilation testing (Observator air volume flow meter), viii) Energy monitoring and ix) Indoor air quality measurements (Graywolf DirectSense IAQ).

Temperature, relative humidity and carbon dioxide (CO_2) levels were monitored in the main bedroom, living room and kitchen of the selected dwellings during summer and spring/winter seasons, with simultaneous measurements of external conditions. Monitoring equipment was positioned away from direct pollutant sources, in accordance with ISO: 16000:1. An occupant diary was employed to gather information on occupancy levels and activities during the measurements. Environmental data was collected at 5 minute intervals.

Figure 1. Case Study Housing projects at Site A

Figure 2. Case Study Housing projects at Site C

Table 1. Dwelling characteristics

Code	Ventilation strategy	Site	Typology	Orient-ation	Floor area	Sun-space	Occupancy	Home occupied	Airtightness ($m^3/h/m^2$)
PS1A	Passive stack	A	Semi-detached	N/S	108 m^2	Yes	2A, 3C	Evenings & weekends	4.76
PS2A	Passive stack	A	Semi-detached	NE/SW	107 m^2	Yes	2A, 5C	All day	5.60
ME1B	dMEV	B	Semi-detached	N/S	107 m^2	Yes	2A, 2C	Evenings & weekends	5.99
ME2B	dMEV	B	Semi-detached	E/W	88 m^2	Yes	3A	Evenings & weekends	5.42
MV1C	MVHR	C	Ground floor flat	N/W	83 m^2	No	2A	All day	---
MV2C	MVHR	C	Ground floor flat	N/W	77 m^2	No	2A	All day	11.13
MV3C	MVHR	C	Ground floor flat	S/W	56 m^2	No	1A	All day	---
MV4C	MVHR	C	First floor flat	N/W	77 m^2	No	2A 2C	Evenings & weekends	---

Results

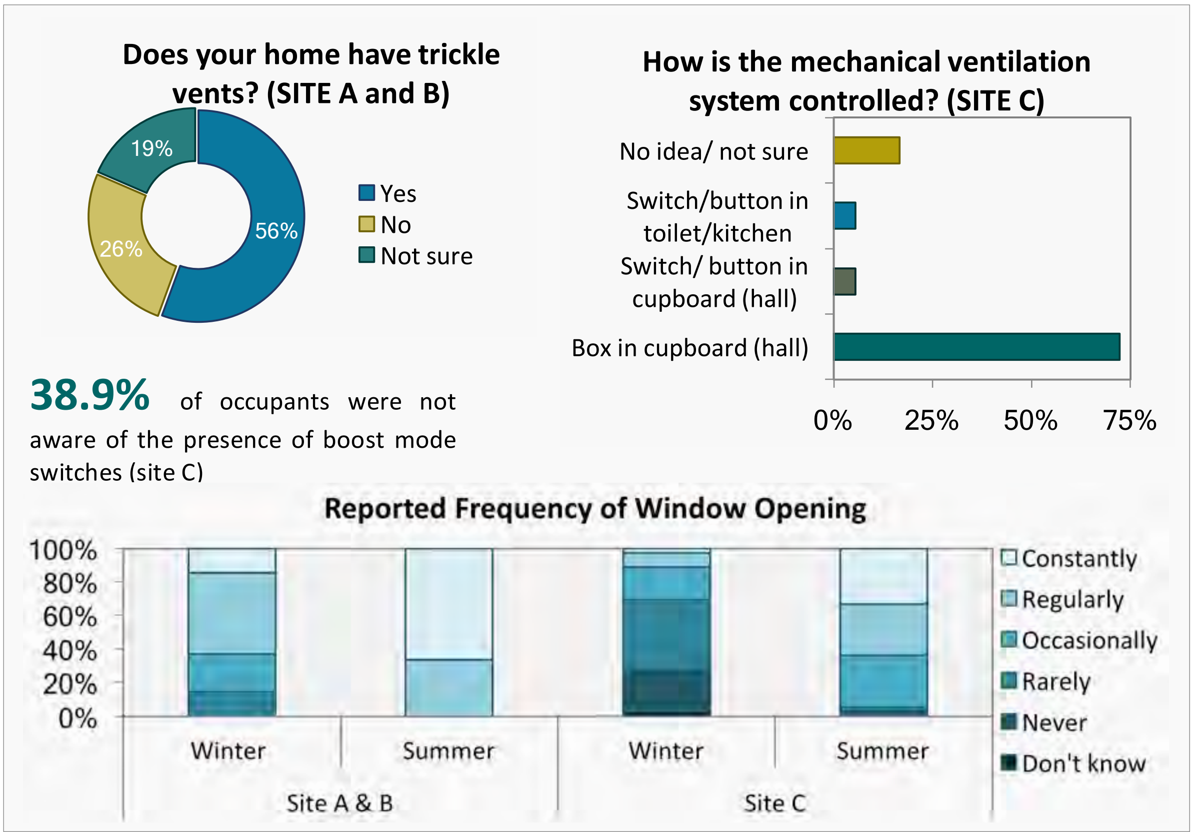

Figure 3. Household Survey results

The household survey identified a lack of occupant awareness and understanding regarding ventilation strategies in both mechanically ventilated and naturally ventilated dwellings. As illustrated in Figure 3, in homes with dMEV and passive stack ventilation (site A & B), only 56% of households were aware of the presence of trickle vents, with 26% stating that trickle vents were not present. Most households at site A&B stated that mechanical extract fans were present in their home (93%), despite many utilising passive stack ventilation (PSV). Nevertheless, 82% of households reported that they were shown how to ventilate their home during the handover process.

Similarly, at Site C (MVHR homes), although all households were aware of the presence of the ventilation system, there appeared to be a general lack of understanding regarding how the system was controlled. 39% of households were unaware of the presence of boost switches in their home to boost the ventilation rate. Of those aware of these switches, 55% stated that they were never used. Nevertheless, 89% of households at site C stated that they have never had any issues with the MVHR system. Issues that were reported included the build-up/creation of dust (6%), discolouration (3%) or faults with the ventilation system (3%).

These results correspond with the findings from detailed monitoring in the eight case study dwellings. For example, the detailed investigation found that most dMEV systems had been turned off by the building occupants at the local isolator switch (during spring and summer visits), which is likely to result in inadequate ventilation. Similarly, in homes with adjustable vents (site B); half of these were found to be in the closed position. Interviews with the building occupants revealed that dMEV systems were turned off because they were perceived to be too noisy. This was supported by the results of sound measurements in one dwelling, were levels exceeded 35 dB LAeq with the MEV system in operation.

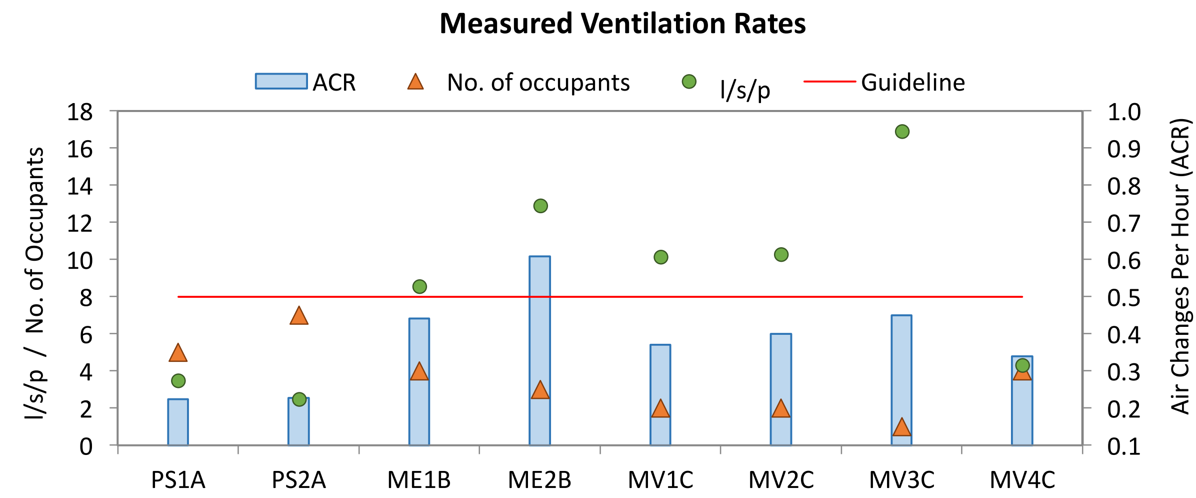

Figure 4. Measured ventilation levels

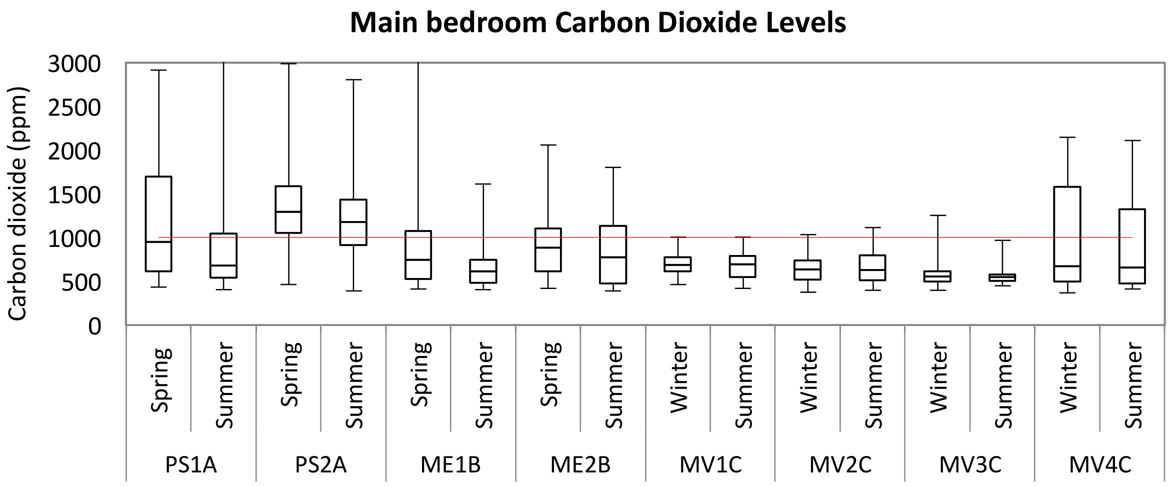

Figure 5. Bedroom carbon dioxide levels

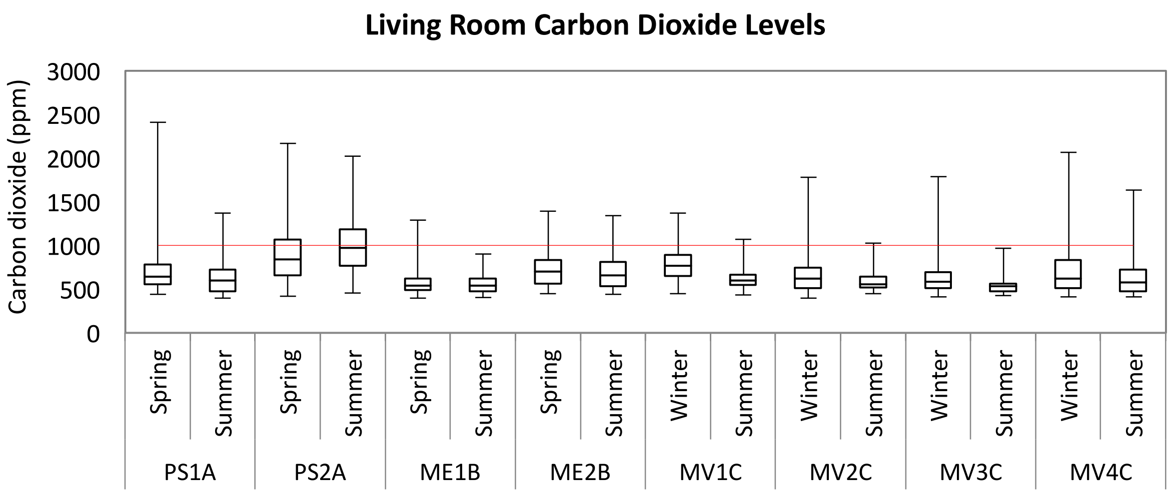

Figure 6. Living room carbon dioxide levels

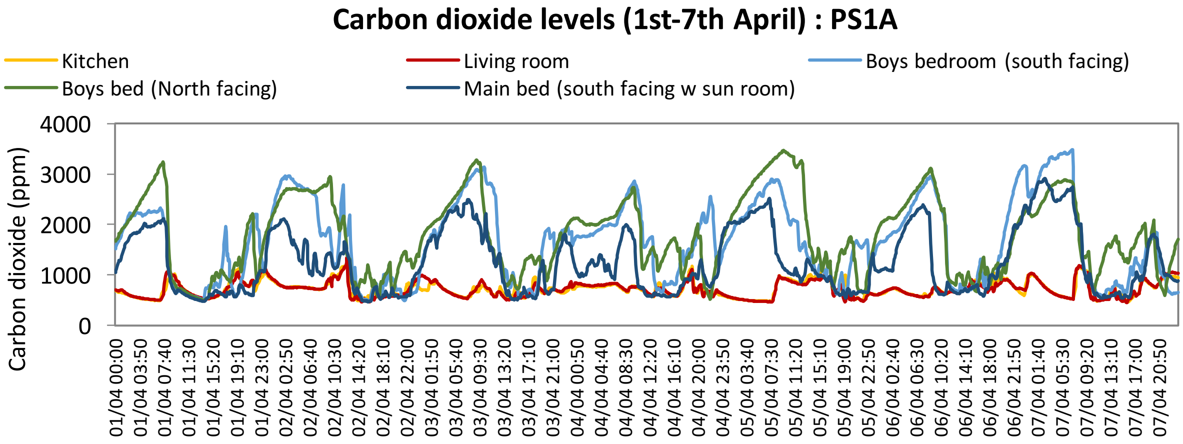

Figure 7. Carbon dioxide levels in PS1A

Physical monitoring in the case study dwellings revealed inadequate ventilation in the majority of homes. Specifically, in the four homes with MVHR systems at site C, measured flow rates (during summer and winter) did not meet design targets under normal operation. In two of these flats, a significant imbalance (>50%) was identified between supply and extract rates (favouring extract). In one home (MV2C), the detailed inspection revealed that the living room supply vent had been closed tight by the building occupants during the winter months, due to complaints of draughts. At site B, although measured extract rates in the two homes with dMEV conformed to Scottish Building Regulations, ventilation rates were likely to be inadequate given that most of these systems were deactivated by building occupants. Measurements of extract rates in two homes with PSV at site A suggest low levels of ventilation (0.22 – 0.23 ach), however these results are dependent on external conditions at the time of measurements.

Ventilation requirements in buildings are inherently linked to building occupants (Bischof et al, 2013); therefore ventilation rates are expressed with reference to the number of occupants (l/s/p), in addition to room volume (ACR). Carbon dioxide (CO_2) is often used as an indicator of ventilation levels in buildings, with levels above 1,000 ppm suggesting inadequate ventilation. Figures 4-6 present the results of physical measurements of ventilation performance in the eight case study homes. As illustrated, only one dwelling (ME2B) satisfied ventilation guidelines of both >0.5 ach and >8 l/s/p (corresponding to approximately 1,000 ppm). However, it is important to note that ventilation measurements in this home were taken when the dMEV systems were in operation, which was not representative of normal conditions. In four monitored dwellings, although ventilation rates greater than 8 l/s/p were measured, air change rates below the recommended 0.5 ach were found.

CO_2 levels peaked above 1,000 ppm in all monitored living rooms and main bedrooms during winter/spring seasons. Average CO_2 levels exceeded 1,000 ppm in the main bedroom of the two homes with passive stack ventilation (PS1A and PS2A) during spring monitoring, and in one home with passive stack ventilation during summer monitoring (PSA1). As illustrated in Figure 7, bedroom CO_2 levels were consistently high overnight in PSA1, suggesting inadequate night-time ventilation.

Discussion

This study sought to identify the degree (if any) of ventilation and environmental performance gaps, determine possible causes of these gaps and provide knowledge and insight to inform current and future developments. The household survey provided the opportunity to gain an insight into the overall performance of dwellings, while detailed monitoring helped to gain a more in-depth understanding of the possible causes of performance gaps and the potential implications of these.

The results from the household survey suggest a lack of understanding of ventilation methods in the homes. This includes confusion regarding the operation and purpose of MVHR systems (at site C), and a lack of awareness of trickle vents and confusion between passive and mechanical ventilation strategies (at site A and B). These findings are supported by the results of the detailed building surveys, which found most dMEV systems had been turned off due to complaints of noise and many adjustable trickle vents had been closed by the building occupants. Automatic humidity-sensitive trickle vents were installed in the homes with PSV, which could not be adjusted by the building occupants. Although there was no evidence of MVHR systems being deactivated in the monitored flats at site A, this is difficult to establish without prolonged metering of the ventilation system. It is important to note that whilst occupants seemed to have been briefed to refrain from interfering with the system, switches were available to deactivate the system, if they so wish to do so.

Nevertheless, households reported a high frequency of window opening, particularly during the summer season. Homes with PSV and dMEV reported a higher frequency of window opening than those with MVHR systems. However, reliance on occupants' awareness of the need for increased ventilation and subsequent response (in the form of opening windows) may be insufficient at night while occupants are asleep. This was apparent, for example, in house PS1A, where high night-time bedroom CO_2 levels evidenced poor ventilation. The findings are supported by similar studies that identified significant issues with bedroom ventilation provision (Bekö et al, 2010; McGill et al, 2015; Sharpe et al, 2014).

An important finding from the physical monitoring was the high levels of CO_2 (and low measured air change rates) in the case study dwellings. These may be attributed, in part, to occupant interference with the ventilation strategies, in the form of closing supply vents, turning off dMEV systems or closing trickle vents. The results are in agreement with those obtained by similar Building Performance Evaluation studies that identified concerns regarding ventilation noise, perceived freshness of air, perceived control, complexity and accessibility of control interfaces, and lack of understanding of ventilation in contemporary homes (Gupta and Dantsiou, 2013; Macintosh and Steemers, 2005).

Despite insufficient flow rates and lower reported window opening, bedroom CO_2 levels were generally lower in monitored homes with MVHR systems. MV4C is a notable exception; which highlights the potential risk of poor ventilation in homes dependent on MVHR. These findings however need to be envisaged in light of the poor measured airtightness (in MV2C) and lower levels of occupancy (MV2A, MV2B, MV2C) in these homes, which is likely to have significantly influenced the results. As such, the results highlight the importance of context in ventilation investigations, and support the need for detailed case studies to gain an in-depth understanding of the problem and the range of factors at play.

Nevertheless, the suggestion that modern airtight homes with MVHR systems may be better ventilated than those ventilated naturally is not surprising, given the ability of MVHR systems (in theory) to provide a continuous supply of air to a building. The findings are supported by similar studies that have demonstrated significant issues with natural ventilation strategies in contemporary housing (Dimitroulopoulou et al, 2005; Sharpe et al, 2014).

However, the application of MVHR systems in new-build dwellings represents a step change in domestic ventilation practices and as such, requires careful consideration to ensure effective design, installation, performance, maintenance and operation, particularly in a social housing context. The move towards MVHR raises further concerns, such as the longevity of systems and components, the degree of occupancy control (and resulting satisfaction), the complexity, responsiveness and transparency of systems, and the need to reduce carbon emissions (despite increasing mechanisation of buildings). These challenges need to be addressed to ensure effective, efficient, user-friendly and environmentally responsive ventilation solutions for contemporary housing.

Conclusion

The poor performance of ventilation in the majority of case study dwellings, regardless of the ventilation strategy employed, highlights the fundamental need for improvements to ventilation provision in contemporary housing, particularly those designed to high levels of airtightness. Issues with end-user engagement and interaction in homes with dMEV and MVHR suggest significant advancements are required to ensure these systems are designed and installed in a way that is user-friendly, transparent, engaging and even captivating to building users. It is hoped that the findings of this study might help to shed light on potential causes of ventilation performance gaps in contemporary housing, whilst highlighting the need for greater consideration of the end user in ventilation design.

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Assessment of Natural Ventilation for Air Renewal and Thermal Comfort in Offices in Mexico City

Elisur Mogollon[1], Gloria Castorena[1], Victor Fuentes[1] and Pablo La Roche[2]

[1] Postgraduate in Bioclimatic Design, Division of Science and Arts for Design, Universidad Autónoma Metropolitana, Mexico City, Mexico, email: elisurmogollon@gmail.com; gmce@correo.azc.uam.mx; ffva@correo.azc.uam.mx;
[2] Faculty of Architecture, Cal Poly Pomona University, Los Angeles, USA, email: pmlaroche@cpp.edu

Abstract: In order to achieve thermal comfort and the renovation of air in buildings, natural ventilation has been relegated by mechanical and conditioning systems. These are commonly designed without taking into account the climatic conditions or the needs of the user and they are responsible of a large percentage of respiratory diseases. For the present study, a nucleus of offices located in the Metropolitan Autonomous University, in Mexico City, was analysed. User surveys were applied and measurements of temperature, humidity and wind speed during the pre-occupation period and the warm period were made. The measurements showed an increase of the temperature in the working days and a correlation with the answers of the occupants was observed. On the other hand the relative humidity stays in acceptable ranges of comfort; between 55% and 40%, due to microclimatic conditions. Currently, the wind does not influence the users' thermal sensation. The measurements show areas with greater air movement, generally in the perimeter of each zone, probably originated by the interior distribution and the occupation. The positive and negative effects of ventilation should be evaluated, which will focus on dissipating heat gains due to the occupation and operation of the building.

Keywords: Natural ventilation, thermal comfort, heat gains, air movement, air quality.

Introduction

Currently, the use of natural ventilation in a building has been limited by the use of conditioning systems and mechanical ventilation, which are designed without taking into account local climatic conditions and in many cases without regard to occupation and operation of the building. According to OMS, 75% of chronic diseases of the human respiratory system are mainly due to the inadequate conditions of their living spaces (García et al, 2005). This coincides with data from real estate specialists, which show that at least 30% of the employees working in the nearly 200,000 public and private offices in Mexico, suffer from diseases associated with poor design of ventilation in buildings (El Universal, 2013).

With regard to energy consumption, the energy used for air conditioning and mechanical ventilation can represent up to 50% of energy consumption, depending in part on regional climatic condition (CONUEE, 2015). The energy consumption by using air conditioning and mechanical ventilation is very high and brings with it great economic costs and serious environmental and health consequences.

An adequate design of natural ventilation will benefit the health of the occupants, providing an adequate indoor environmental quality. Taking into account bioclimatic strategies in the development of a project will reduce dependence on artificial ventilation systems, contributing to the comfort conditions in the environment, as well as the reduction in the use of energies that propitiate the global warming and the deterioration of the environment.

Analysis of offices of Direction CyAD

As a case study, a nucleus of offices located at the Universidad Autónoma Metropolitana, in Mexico City was analysed (19°30’11” N / 99°11’13” W, and 2,240 m above sea level). The climatic condition is “semifrío seco”, based on the bioclimatic grouping of Fuentes and Figueroa (1988). The weather is: BS1kw(w)(i’)g according to the Köppen García classification (García, 1973), which is described as dry with little thermal oscillation and without presence of heat. The zone have ranges of average outdoor air temperature between 13.5°C and 19 °C, with a maximum of 26.7°C and a minimum of 4.7°C., with a total annual precipitation of 592 mm and a relative humidity of 50% with an ± 6 oscillation. The dominant winds have a South-West direction with prevailing winds in the same direction. Calms account for 24%.

The offices are located on the ground floor of University, Building H (See Figure 1). The access is located in the central courtyard of this building. The construction is made of of block, reinforced concrete and aluminium glazing with clear glass of 6 mm. The internal divisions are of gypsum board with vinilyc painting, aluminium glazing with clear crystal of 6 mm. And louver in the enclosures.

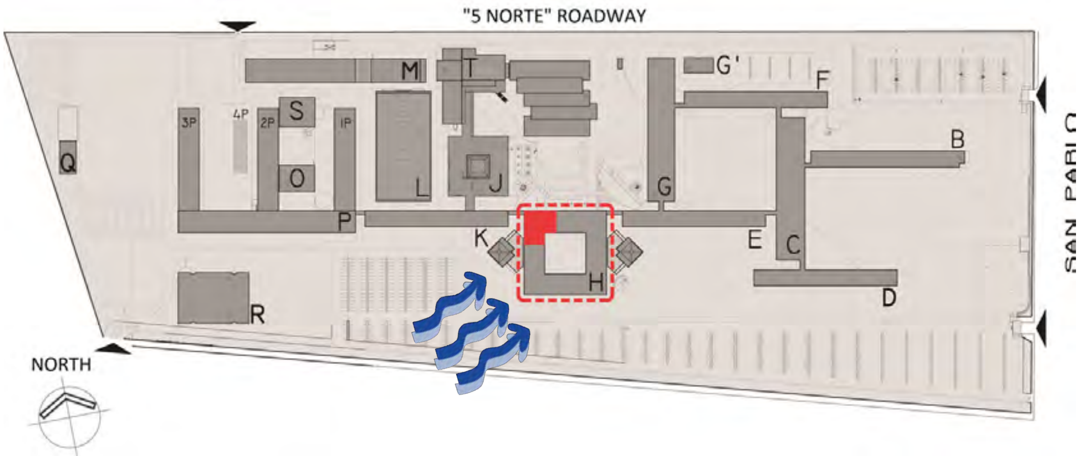

Figure 1. Location of Direction CyAD offices. UAM-Azcapotzalco

The offices have a constructed area of 334 m2 and a height of 2.60 m / 3.00. They consist of a series of private cubicles and group spaces, the cubicles communicate through a common area, where there are open workstations. The offices have natural ventilation, supported by mechanical extractors in some of their spaces. The window area represents almost a third of the total building area, however the area of operable windows is barely 8 m2, which is 8% of the surface of openings and 2% of the total construction surface. It is important to note that the openings are protected from direct solar radiation by an exterior eave on all its facades. The architectural distribution and the location of the measurement points are shown in figure 2.

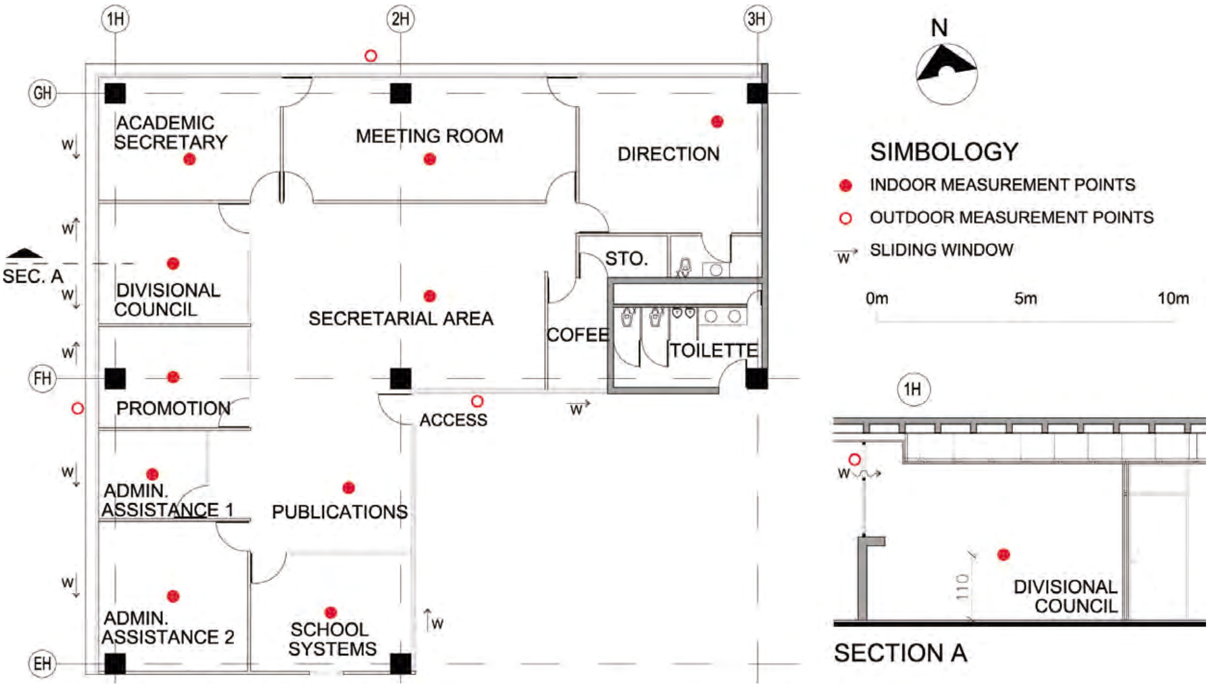

Figure 2. Architectural plan, offices. UAM-Azcapotzalco

The classification of areas was done in spaces with occupation and without occupation. The offices are occupied by 20 users of full time, the majority are in a range of age between 35 and 64 years; they are dedicated to administrative activities, which develop seated. The metabolic rate is 1.0, with a CLO factor of 0.89, which corresponds to overalls, long-sleeve shirt, t-shirt, according to the parameters of ASHRAE 55-2013. The classification of areas is shown in table 1.

Table 1. Classification of areas. Offices of CyAD

Private areas	Group areas	Non-occupancy spaces
Direction	Secretarial area	Coffee area
Academic secretary	Meeting room	Storage
Divisional council	School systems	
Income and promotion	Administrative assistance 2	
Administrative assistance 1		

Thermal conditions

In order to determine the thermal conditions of the space, measurements of air temperature, inside and outside, relative humidity and air velocity were carried out in accordance with the requirements of ASHRAE 55-2013, this during two different periods: pre-occupation and warm period. Graphs from an average of 24 hours were plotted. They also include the comfort zone defined by the Neutral Temperature (Tn), with a thermal amplitude of ± 2 K according to the linear equation of Auliciems (Auliciems and Szokolay, 1997) for adaptive comfort:

$$Tn = 17.6 + 0.31\, Tmed$$

Figure 3 shows the daily average of the measurements made in the month of February, prior to the occupation. It is perceived that the interior temperature conditions are slightly cold throughout the day, with little thermal oscillation (3 K), and very different from the outside, where there is an oscillation of 9 K, with temperatures ranging from 17 At 26 ° C. This can be attributed to that the windows do not have direct incidence of the sun, so the space is not affected by variations of the conditions of the outside environment.

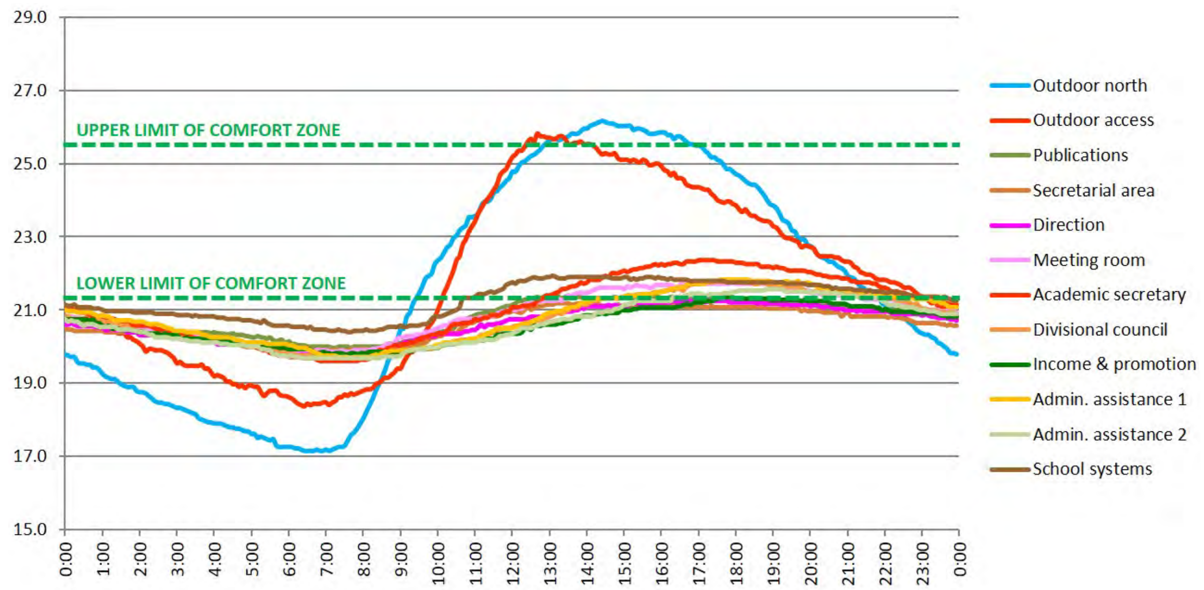

Figure 3. Average temperature in 24 hours. Pre-occupancy period

Figure 4 shows the average daily temperature in the warm period, which occurs in May. In contrast to the unoccupied period, the graph shows how the occupation and operation of the space has a significant influence on the interior temperature, since there is an increase in temperature in the working days (Monday to Friday) between 10:00 AM and 7: 00 PM.

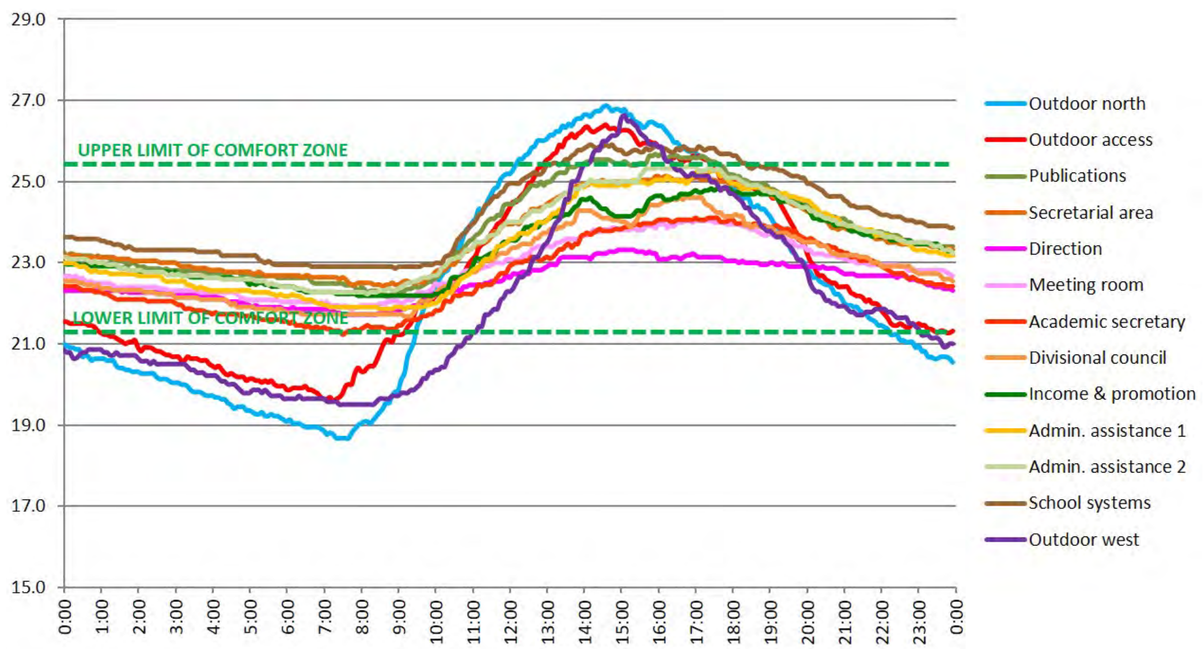

Figure 4. Average temperature in 24 hours. Warm period

During the warm period, the outside temperature is maintained between 19 °C and 27 ° C and the indoor temperatures range from 21.5 ° C to 26 ° C. Half of the spaces are located near the upper limit of the comfort zone. Variations in temperature are due to several factors: number of users per space, working hours and in some cases the level of control that occupants have to achieve comfort in their work areas, such as operable windows, mechanical extractors and individual fans.

Relative Humidity Analysis

In order to know the levels of humidity saturation in the space and its affectation in the occupants, a daily average of the relative humidity of the warm period was made (see Figure 5). With a maximum HR of 65% at 7:00 AM on the outside and a minimum of 35% at 3:00 PM. The indoor relative humidity is stable at night, with a maximum of 53% at 10:00 AM in the Direction office and a minimum of 40% in the secretarial area at 3:00 PM. Although there are significant variations of relative humidity, this is always in acceptable ranges of comfort; between 55 and 40%, according to the hydric comfort parameter ± 20% from 50% RH (Fuentes, 2004), even though the site is classified as "Semifrio-Seco" according to the bioclimatic grouping of Fuentes and Figueroa (1988). Therefore it is concluded that microclimatic conditions prevail in the University environment, due to the amount of green areas adjacent to the offices.

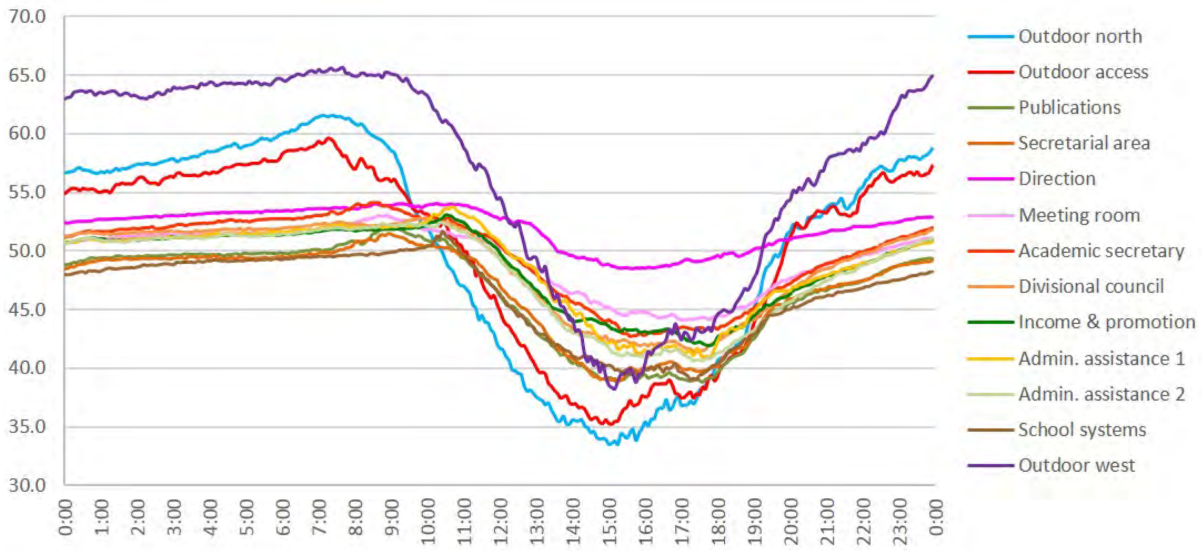

Figure 5. Average relative humidity in 24 hours. Warm period

Wind analysis

Wind measurements during the warm period were made, with hot wire anemometer. Average velocities of 0.05 m/s were recorded in open spaces with direct incidence of external wind, and velocities of 0.01 m/s in cubicles and closed areas. It follows, therefore, that currently the speed of the wind to the interior does not influence the thermal sensation of the users, reason why adjustments to take advantage of the natural ventilation must be made. The measurements also showed that there are areas with greater air movement, close to the limits of the space, but not less than 0.30 m away from the walls or obstructions

Since vegetation and architecture play an important role, it was sought to establish the parameters of wind behaviour outside the offices. Wind measurements were performed around the building every 3 minutes during the one hour interval to record wind behaviour patterns. With this information the wind velocities were determined, with a speed air average of 1 m/s and a maximum of 1.5 m/s, without exceeding 2 m/s, with a west direction in the north facade, and South-West direction in the west facade, and absence of wind on the south east facade. These data coincide with the collected climatic information.

Hygrothermal comfort surveys

In order to correlate the results of the comfort model with the indoor temperature conditions, user surveys were applied during the hot period, to a total of 18 occupants, according to ASHRAE 55-2013. Although this sample is not representative to validate similar studies, it is for the present case, as established by the reference standard. Perceptions of temperature and humidity of the users are shown in Figures 6-7, which coincide with the thermal conditions obtained in the measurements.

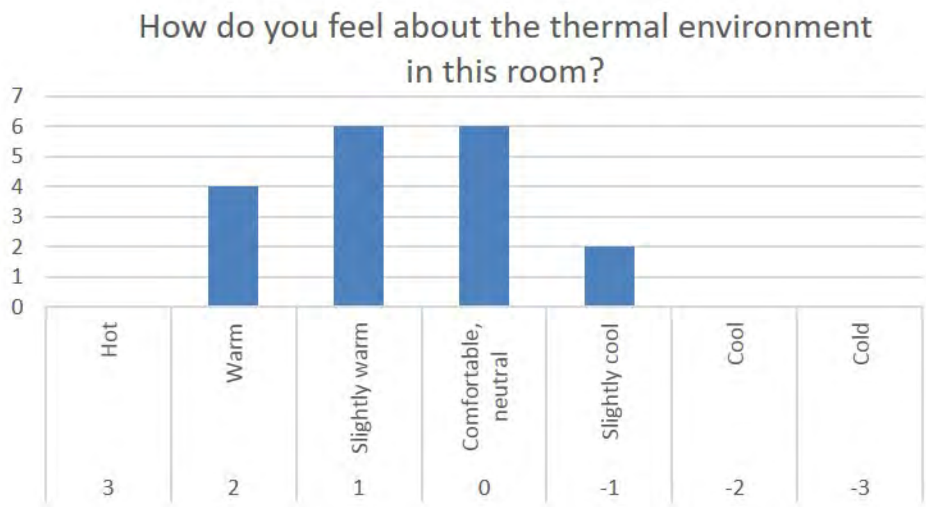

Figure 6. Temperature perception of occupants

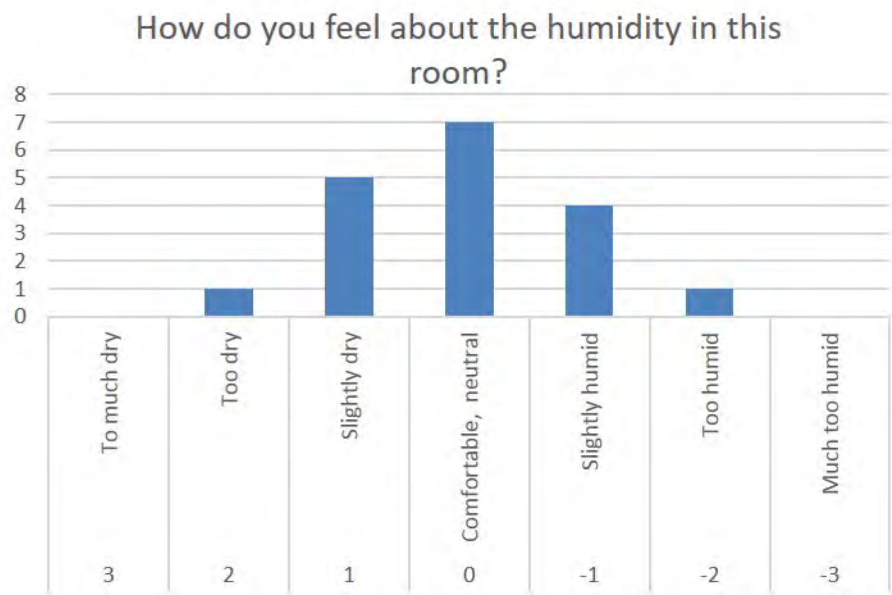

Figure 7. Humidity perception of occupants

Perception of ventilation is an important factor of the study, 50% of the respondents perceive a light ventilation inside the spaces, however, 44% perceive no ventilation and only 6% indicates a medium level of ventilation. The trend is confirmed by occupant ventilation preferences, as 81% would prefer higher levels of ventilation and only 6% indicate that they would like less ventilation, while 13% are satisfied with the supplied air.

Discussion

Based on the thermal analysis and the current conditions we can say that thermal comfort is a problem in half the spaces, and the rest are in comfortable conditions: Direction, Academic Secretary, Meeting room, Divisional council and Income and promotion. The rest of the zones are in thermal conditions near the upper limit of comfort. The most problematic spaces are located on the south-west side, which indicates that it is possible to take advantage of the external wind conditions to promote heat loss through ventilation. A simple calculation determines the potential of ventilation. According to the formula of R. Aynsley (cited by Fuentes, 2004), it is possible to estimate the speed of the wind necessary to restore the thermal comfort in the spaces. Entering the value of the maximum comfort limit of the case study:

$$v = 0.15\ [T - 25.4 + 0.56\left(\frac{HR - 60}{10}\right)]$$

This indicates an increase in the air velocity with which the interior comfort levels would be restored in the 5 areas with comfort problems, as shown in Table 2:

Table 2. Wind speed required

Space	Max. indoor temp.	Required air speed (m/s)
School systems	25.9	0.24
Publications	25.6	0.19
Administrative assistance 2	25.4	0.15
Administrative assistance 1	25.0	0.09
Secretarial area	25.1	0.12

The rest of the spaces, are in acceptable levels of comfort, reason why the requirements of ventilation are limited only to the air renovation. This shows that with some adjustments to the ventilation openings the requirements could be met and adequate levels of comfort can be achieved during the warm season.

Conclusions

There is a correlation between the results of the measurements and the surveys applied to the users. According to the analysis of the temperature, there are comfort conditions in the middle of the spaces during the warm season, however, there are areas that require adjustments to improve thermal conditions, such as School Systems, Publications and Administrative assistance 2, which are the areas with the highest occupancy.

Although a third of users find their work environment comfortable, and half of them perceive a light ventilation feel, most of them would want a cooler, more ventilated environment, and all spaces must increase ventilation levels to improve indoor environmental quality. This indicates that, although the thermal factor influences the environment conditions, air quality and quantity are important.

Although the wind conditions are minimal, the measurements show areas with greater air movement, generally in the perimeter of each zone, probably by small turbulences originated by the interior distribution and occupation. More detailed measurements are recommended to establish patterns of wind behaviour in each of the zones. It is established that the velocity of the air and its distribution within a space is not uniform, however, it is convenient to consider an average internal air velocity that helps determine the ventilation rates in the space.

Because there is no direct solar gain on any of the facades, the use of ventilation will be mainly used to dissipate heat gains, due to the metabolic heat of the occupants and the radiation of electronic equipment.

For comfort requirements, the effect that the wind has on the space must be evaluated both positively and negatively. In the warm season, small entrances are advised, directing the flow towards the zones of activity and great exits to propitiate an adequate air flow, as well as a free distribution without elements that hinder the inner flow and block their flow during the winter.

Due to the size of the sample studied, these conclusions are unique to this specific case, and cannot be validated for similar projects, so that similar cases should analyze their specific climatic conditions, space design and occupation.

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The Pacific Breezes: Estimation of the overheating risk and the natural ventilation potential for buildings in cities of the Chilean Pacific Coast

Massimo Palme[1], Claudio Carrasco[1] and Miguel Angel Gálvez[3]

[1] School of Architecture, Catholic University of the North, Antofagasta, Chile
[2] Faculty of Engineering, University of Valparaíso, Valparaíso, Chile
[3] Faculty of Architecture, Technical University Federico Santamaría, Valparaíso, Chile

Abstract: Global Warming and Urban Heat Island are phenomena that are worsening the building energy performance, increasing the cooling demand in summer time of any kind of buildings. Moreover, accomplishing the most restrictive laws on energy savings (principally developed to avoid thermal losses during the cold season), is leading in many countries to a substantial overheating of the spaces in summer and in some cases even in winter. One of the best strategies to avoid overheating is the use of natural ventilation, especially where breezes are almost constant during the day and year. This is the case of the long Chilean Pacific Coast, where many of the most important cities of the country are placed. This paper compares a steady-state evaluation method and dynamical simulations to estimate the cooling demand of family houses and the reduction of this demand due to the use of natural ventilation (wind driven) in eight cities. Results show that the more than the 30% of the cooling demand could be eliminated by natural ventilation systems. The inclusion of this kind of evaluation in the buildings energy certification system could benefit the entire country in terms of energy demand and greenhouse gases emissions reduction.

Keywords: Cross-ventilation, overheating, passive cooling, thermal codes, Chile

Introduction

During the last 50 years, the concept of “passive architecture” and the need of reducing energy consumption and greenhouse gases emissions have been constantly related. However, in some cases good intentions load to wrong results. It is the case, for example, of many bioclimatic buildings that are very sensitive to changes in the environment like urban heat island or global warming (Toledo, 2016; Palme, 2015; Palme et al., 2016a; Jenkins et al., 2009). Most of the design rules applied today, can lead to a wrong building performance in the near future, basically due to excess of heat in summer. To avoid the overheating sensation of users without increasing the energy consumption, especially of electricity, is a challenge for the architecture of the XXI Century. In countries like Chile, the challenge is even more important, because of the change in the purchasing power of the middle class family. Today, residential buildings are normally naturally ventilated and have no cooling systems. However, this situation can change drastically in the next years. Residential buildings constitute more than the 70% of the total built environment and the impact of the sector on the total energy consumption could be very high.

Methodology

In this paper a steady-state assessment (based on the ISO 13790) is done in order to establish the overheating risk and the natural cross ventilation potential to evacuate the heat in excess during the summer season, considering 90 days (from January to March). A set of simulations was performed with the natural ventilation option available in Design Builder, in order to control the results capability. Design Builder was selected because of the facility in the result comparison with and without natural ventilation (Tronchin 2008). A family house is evaluated in different conditions of orientation facing the wind (90º or 45º) and of internal distribution (well connected or poorly connected). Emplacements studied are the Chilean cities (from North to South) of Arica, Iquique, Antofagasta, La Serena, Valparaíso, Concepción, Valdivia and Puerto Montt. All these cities are coastal cities in a region of the world characterized by constant and intense breezes from the sea to the land (land-sea breeze is sometimes present but not constantly, due to the effect of the Andean Cordillera on the air flows). In this study, the wind is supposed always coming from S-W, without modifications due to the urban environment.

Overheating risk calculation

Overheating risk is calculated by using a method based on the EN ISO 13790 (2008), which considers average daily temperatures and a correction to take into account the heat accumulation in the thermal mass. To estimate the overheating, many factors are considered. The following equations resume the method. First term to be considered is:

$$SGO = R \times S \times \alpha \times R_{es} \times U \tag{1}$$

Where:

SGO is the solar gain through the opaque envelope elements (J)
R is the incoming solar radiation (J/m^2)
S is the surface of the opaque element (m^2)
α is the solar absorption of the surface
R_es is the external surface thermal resistance (m^{2}K/W)
U is the transmittance of the element (W/Km^2)

The second term is:

$$SGW = R \times S \times f_f \times f_{sg} \times f_{mp} \times f_a \tag{2}$$

Where:

SGW is the solar gain through the windows (J)
R is the incoming solar radiation (J/m^2)
S is the surface of the element (m^2)
f_f is the framework coefficient of the window
f_{sg} is the solar factor of the glass
f_{mp} is the factor of mobile protection of the window
f_a is the accessibility factor due to external shadows

The third term to be considered is:

$$IG = \sum P \times S \times t \tag{3}$$

Where:
IG is the internal heat gain (J)
P is the heat generated by each appliance and by people (W)
S is the floor surface of the zone (m^2)
t is the time of functioning or occupation (s)

The total gain is expressed by:

$$TG = IG + \sum SGO + \sum SGW \tag{4}$$

Part of this heat is evacuated by thermal transmission trough the envelope and the other part represents the overheating OH:

$$OH = TG - \ (T - T_A) \times H_t \times \eta \tag{5}$$

Where
T_A is the daily average temperature (ºC)
T is the internal temperature (set as adaptive comfort temperature)
H_t is the thermal loss (J/ºC) by transmission trough the envelope
η is the efficiency of the heat loss and depends on the thermal mass

Adaptive comfort concept refers to the maximum temperature that people used to live in free-running buildings will accept as comfortable. This temperature depends on the external temperature and has been expressed by different experimental formulas (De Dear and Brager, 1998 and 2002). In this paper the expression used is:

$$T = \max(0.35\, T_A + 17.8\, ; 26) \tag{6}$$

Meteorological data used in calculation are obtained by ASHRAE (temperatures) and by using epw files (solar radiation) produced by Meteonorm tool and processed by using TRNSYS 17 in order to obtain the radiation on the vertical surfaces. Table 1 resumes the data (average temperatures and total radiation during the summer season (January-March).

Table 1. Radiation and temperature for the considered cities

	H(MJ/m^2)	N(MJ/m^2)	S(MJ/m^2)	E(MJ/m^2)	W(MJ/m^2)	T_A (°C)	T 8-20h
Arica	2040	740	704	1210	1110	22.6	24.9
Iquique	2125	775	675	1206	1180	21.9	23.4
Antofagasta	2160	817	625	1240	1170	20.1	22.8
La Serena	1880	882	629	1170	1040	17.3	20.3
Valparaíso	1670	835	599	1030	958	21.5	25.2
Concepción	1877	980	591	1134	1128	16.2	19.0
Valdivia	1650	950	582	1021	1017	15.2	18.3
P. Montt	1547	931	545	970	960	13.7	15.7

Natural ventilation assessment

Natural ventilation potential is estimated by using a simplified method, also following EN ISO 13790. To evaluate the natural ventilation capacity to evacuate heat, the following equation can be used:

$$NVH = (T - T_v)\times(H_v)\times\eta \tag{7}$$

Where:

NVH is the heat removed by natural ventilation (J)
T_v is the air temperature (daily average or 8-20 average depending on the case) (ºC)
H_v is the thermal loss (J/ºC) by ventilation
η is the efficiency of the heat loss

The thermal loss by ventilation is expressed as:

$$H_v = t\times\delta\times sh\times q \tag{8}$$

Where:
t is the period (s)
δ is the density of the air (kg/m^3)
sh is the specific heat of the air (J/kgK)
q is the flow (m^3/s)

The airflow has to be assessed by analyzing the geometric characters of the house and the windows typologies and depends on few parameters: two discharge coefficients cd,i and cd,o (inlet and outlet of the air), two pressure coefficients cp,I and cp,o (on the façades where the windows are placed) and one internal coefficient ci (depending on the space distribution and connection).

The final formula is:

$$q = v\times\sqrt{\frac{|c_{p,i}-c_{p,o}|}{\frac{1}{c_{d,i}^2\times s_i^2}+\frac{1}{c_i^2\times s_d^2}+\frac{1}{c_{d,o}^2\times s_o^2}}} \tag{9}$$

Where s are the surface of inlet, distribution and outlet respectively.

Final heat to be removed (FRH) can be expressed as:

$$\text{FRH=OH-NVH} \tag{10}$$

By comparing the overheating OH and the final heat to be removed FRH the effectiveness of the natural cross-ventilation can be obtained.

Two house orientations respect the wind and two internal distributions are tested in this work. Figure 1 shows the well connected and the poorly connected distribution of the houses. Table 2 shows the house and windows dimensions. The house has only two windows, on each of the main façades. Pressure coefficients depend on the relationship height/width and length/width of the house. Table 3 resumes the coefficients used and the air flows calculations for the two considered orientations. Air speed used is 1 m/s. Details for coefficient calculation are described in many contributions, like the work of Heiselberg and Sandberg (2016).

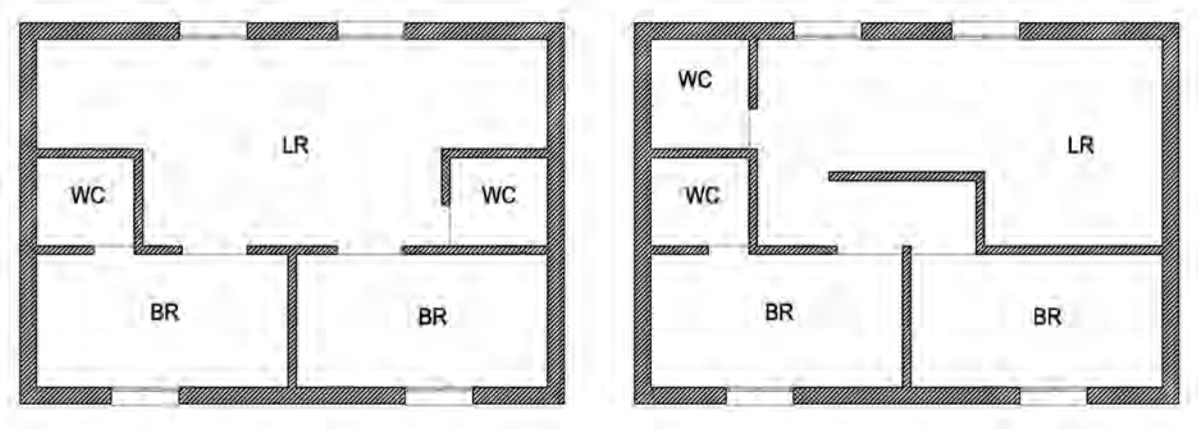

Figure 1. Well connected and poorly connected house

Table 2. House dimentions

	H (m)	L (m)	W (m)	S (m^2)	H/W	L/W
House	3.5	10	7	70	0.5	1.43
Windows	1	1	na	1	na	na

Table 3. Pressure coefficients, discharge coefficients and air flow

	Cpi	Cpo	Cdi	Cdo	Ci (wc)	Q (wc)	Ci (pc)	Q (pc)
House 45°	0.10	-0.35	0.70	1.00	0.80	0.94 m^3/s	0.30	0.39 m^3/s
House 90°	0.70	-0.20	0.70	1.00	0.80	1.3 m^3/s	0.30	0.56 m^3/s

Dynamical simulations

Simulations are conducted by using Design Builder tool with and without the "natural ventilation" application available in the tool. The natural ventilation module automatically uses the external air to reduce the overheating when possible and turn on the air-conditioning when necessary (mixed mode). The air flow is calculated by the AIRNET module in Energy Plus. For detailed description, see for example the work of Gu (2007) and the manual of the software. Figure 2 shows the network model. Table 4 shows the transmittance values used in simulation and steady-state evaluation. These values come from the Chilean thermal standard (MINVU, 2008) of the Dwelling Ministry (maximum transmittances per climate zone). Internal gains were set to 25 W/m^2, occupancy was considered of 24 hours.

Table 4. Walls, roofs and windows transmittances (W/m^{2}K)

	Arica	Iquique	Antofagasta	La Serena	Valparaíso	Concepción	Valdivia	Puerto Montt
Wall	4	4	4	4	3	1,7	1,6	1,1
Roof	0,84	0,84	0,84	0,84	0,6	0,38	0,33	0,28
Wind.	5,8	5,8	5,8	5,8	2,4	2,4	2,4	2,4

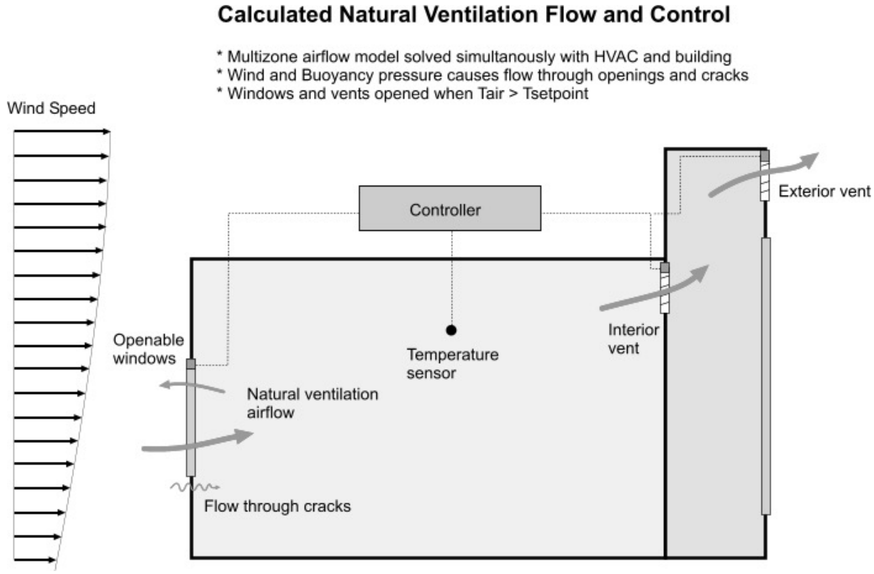

Figure 2. Natural ventilation model (picture from www.designbuilder.co.uk)

Results and discussion

Table 5 resumes the results of the steady state evaluation and dynamical simulation, considering natural ventilation and without considering it. Steady-state evaluation shows energy savings in the range 30-90% depending on the location, orientation and internal distribution. This result is according to previous studies (Palme et al. 2016b). Dynamical simulations results is also according to the steady state evaluation in terms of energy saving. Cooling demand calculated by dynamical simulation is in general lower than the estimated overheating, probably because of simplifications in the steady-state model, especially regarding the calculation of the solar gains. It could surprise that the cooling demand estimated by steady-state analysis is higher in the southern cities like Valdivia and Puerto Montt than in central cities like La Serena, but this fact is explained by the different transmittance values used: southern cities have to use more insulated walls and roofs to accomplish the norm. Besides the difference in the simulated or simply evaluated energy demand, the resulting energy savings obtained by using natural ventilation are very close to the estimations in most of the analysed cities. This general result allows this methodology as a very simple tool that can be incorporate in the actual thermal code of the Housing Ministry, which today is not considering a numerical evaluation of the cooling demand (Palme, 2014; Palme and Vasquez, 2015). The incorporation of energy labelling in terms of natural ventilation performance in the National Energy Certification System will probably avoid the generation of an unnecessary cooling systems demand of the Chilean market.

Table 5. Simulation and steady-state results

	Hourly simulations			Simplified evaluation		
	Cooling demand (kWh/m^2)	With natural ventilation (kWh/m^2)	Saving (%)	Cooling demand (kWh/m^2)	With natural ventilation (kWh/m^2)	Saving (%)
Arica						
House 90º facing wind (wc)	16,50	9,16	44%	53	29	45%
House 45º facing wind (wc)	16,25	11,09	32%	53	35	33%
House 90º facing wind (pc)	16,50	14,32	14%	53	42	20%
House 45º facing wind (pc)	16,25	14,60	10%	53	49	14%
Iquique						
House 90º facing wind (wc)	14,44	7,30	49%	44	7	84%
House 45º facing wind (wc)	14,42	8,99	37%	44	12,5	71%
House 90º facing wind (pc)	14,44	12,31	17%	44	22	49%
House 45º facing wind (pc)	14,42	12,82	11%	44	28	37%
Antofagasta						
House 90º facing wind (wc)	10,67	2,01	82%	21	1,8	91%
House 45º facing wind (wc)	10,65	2,75	74%	21	3,5	82%
House 90º facing wind (pc)	10,67	6,31	41%	21	7	65%
House 45ª facing wind (pc)	10,65	7,68	29%	21	10	50%
La Serena						
House 90º facing wind (wc)	6,63	0,99	85%	3,1	0,1	97%
House 45º facing wind (wc)	6,59	1,25	81%	3,1	0,2	93%
House 90º facing wind (pc)	6,63	2,69	60%	3,1	0,85	82%
House 45º facing wind (pc)	6,59	3,63	45%	3,1	0,56	70%
Valparaíso						
House 90º facing wind (wc)	13,18	9,03	31%	42	24	40%
House 45º facing wind (wc)	13,11	9,75	26%	42	29	30%
House 90º facing wind (pc)	13,18	11,35	14%	42	36	18%
House 45º facing wind (pc)	13,11	11,92	9%	42	31	12%
Concepción						
House 90º facing wind (wc)	4,38	0,80	81%	21	0	100%
House 45º facing wind (wc)	4,35	0,91	79%	21	0,15	99%
House 90º facing wind (pc)	4,38	1,52	65%	20	2,0	96%
House 45º facing wind (pc)	4,35	2,10	50%	20	0,8	91%
Valdivia						
House 90º facing wind (wc)	4,67	1,45	68%	15	0	100%
House 45º facing wind (wc)	4,62	1,71	63%	15	0	100%
House 90º facing wind (pc)	4,67	2,68	42%	15	0,4	97%
House 45º facing wind (pc)	4,62	3,18	31%	15	0,95	93%
Puerto Montt						
House 90º facing wind (wc)	2,69	0,84	69%	19	0	100%
House 45º facing wind (wc)	2,57	0,92	64%	20	0	100%
House 90º facing wind (pc)	2,69	1,30	51%	19	0,1	99%
House 45º facing wind (pc)	2,57	1,58	39%	20	0,35	98%

Conclusion and future work

In this work the wind-driven ventilation has been assessed as a passive strategy to reduce overheating in small houses in Chile. Future work should consider convective ventilation (by temperature differences) and more building typologies. Other interesting issue to be investigated is the influence of the urban heat island (UHI) on the cooling needs, and the modifications in the effectiveness of the natural ventilation due to the same UHI. It seems that increased urban temperatures should generate a forcing effect on the air speed, because of the increased difference between Sea and land temperatures (Lebassi 2011). Other works estimates a global decrease in the natural ventilation potential under UHI effect (Palme et al. in press). Climate change is other topic to be considered in assessing the changes in the ventilation patterns of coastal environments.

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Design to Thrive

Computational Investigation of Natural Ventilation in an Educational Building in Madurai, Tamilnadu

S Subhashini[1], K Thirumaran[2]

[1] Department of Architecture, Thiagarajar College of Engineering, Madurai, India, email-ssarch@tce.edu;
[2] Department of Architecture, National Institute of Technology, Trichy, India, email-ktm@nitt.edu;

Abstract: Natural ventilation in educational buildings plays a vital role in energy conservation, thermal comfort, indoor air quality and reduction of carbon emission. This paper investigates the natural ventilation performance of a School of Architecture building located in the warm humid climatic zone of India. The study involves three phases, an evaluation of occupant's perception on overall comfort (summer, winter and monsoon) using Building Use Studies workplace survey, field measurements of outdoor and indoor weather conditions like temperature, air velocity and relative humidity and Computational Fluid Dynamics (CFD)- based simulations for the whole building. The numerical simulation on the discretized domain is carried out using ANSYS Fluent. The boundary conditions necessary for the CFD study were obtained from the experimental data measurements. The lowest air velocity recorded in the summer month has been considered for the simulation to understand the influence of architectural design of the building on natural ventilation. As a result, the unique characteristics of air flows within classrooms and studios were determined, and ventilation processes in various situations have been analysed, discussed and compared with the BUS survey results to validate each other.

Keywords: Natural ventilation, air flow, Computational Fluid Dynamics (CFD); occupant comfort.

Introduction

Natural ventilation may be defined as ventilation provided by thermal, wind or diffusion effects through doors, windows, or other intentional openings in the building as opposed to mechanical ventilation that is ventilation provided by mechanically powered equipment such as motor-driven fans and blowers. These natural ventilation systems may reduce both installation and operating costs compared to mechanical ventilation systems while maintaining ventilation rates that are consistent with acceptable indoor air quality (Emmerich et al, 2001). Occupants of naturally ventilated buildings are often more tolerant of fluctuations in the indoor climate (Brager, 2001). They tend to accept a wider range of temperature and humidity levels.

Consequently, in the recent decades, many researchers have investigated the airflow patterns, the temperature and contaminant distributions, and thermal stratification comfort as well as the effects of thermal buoyancy and wind force for naturally ventilated rooms or buildings (Nielsen 2002, Ramponi et.al, 2011, Yang et.al. 2014, Calautit et.al, 2015). However, the aforementioned most of researches and experiences of natural ventilation were focusing on the residential and office buildings but very few researches have been carried out for educational buildings in hot climates (Wang et.al 2014, Beltrán et.al. 2015). Classroom environment and thermal comfort has an important role in the teaching and learning as it could be engaging students in activities that promote their performances, such as understanding of concepts, abilities of problem solving, attitudes towards learning, and etc. With the technology of CFD wind environment simulation, architects are able to better forecast and more intuitively describe the building wind environment in a design scheme, and conduct an analysis based on relevant building technologies and simulation results, with which they can make comparisons among various options and improve the design scheme (Guo et.al, 2015). The study involves three phases, an evaluation of occupant's perception on overall comfort (summer, winter and monsoon) using Building Use Studies workplace survey, field measurements of outdoor and indoor weather conditions like temperature, air velocity and relative humidity and Computational Fluid Dynamics (CFD)-based simulations for the whole building. A post occupancy evaluation of the building was also carried out using BUS methodology (Leaman and Bordass 2001) to understand the occupant's perception on thermal performance, lighting and indoor air quality. In this case the thermal comfort results are derived from the mean scores and open ended comments on users' experience and assessment of temperature, air, lighting and overall comfort from the BUS survey data rather than the PMV (Predicted mean vote) model (Fanger 1970) or adaptation model (De dear,1991) . The survey results showed thermal discomfort during summer. Thus field measurements of the indoor and outdoor weather conditions were recorded for the month of March 2016 using hobo data loggers and Watchdog 2700 weather station. Taking the lowest air velocity of the outdoor wind environment from the experimental data the CFD based simulations were carried out to explore the effect of natural ventilation in the building design when wind speed is very low. The main purpose of this study is to understand the influence of building design on natural ventilation and thermal comfort. The numerical simulation results of the airflow properties were very helpful to form a digitized database system and allow us to understand the interaction between the building structures and the urban wind environment.

Building description

The architecture department building is located inside the campus of Thiagarajar College of Engineering; Madurai .It is an isolated two storey building consisting of design studios, lecture halls, an audio visual hall, a library and staff rooms surrounding two courtyard spaces. The building is oriented towards east west axis (Figure 1). It is a naturally ventilated building with fans for mechanical ventilation. Temperatures during summer, in the months of March to June reach a maximum of 40°C and a minimum of 26.3°C**.** Winter temperatures range between 29.6°C and 18°C between the months of December and February (Subhashini 2015). The relative humidity typically ranges from 37% to 96% over the course of the year. Over the course of the year typical wind speeds vary from 0 m/s to 10 m/s. The highest average wind speed of 6 m/s occurs around July and the lowest average wind speed of 3 m/s occurs around March. There are no hills in the region of the Madurai Corporation limit. Therefore, the existing topography of this city experiences horizontally homogeneous wind flow and more or less steady-state meteorological conditions.

Figure 1. Top view of Architecture department, TCE, Madurai

Post occupancy evaluation outcomes

The occupant survey used was the Building Use Studies Survey (BUS) Workplace Questionnaire. The BUS questionnaire is a post occupancy evaluation instrument developed by Building Use Studies, UK. The responses to the variables are sought on a 7-point scale (Thomas and Baird, 2006). In the discussions of survey response means and their standard deviations (SD), reference is made to three types of scale:

- A-type scale where better values are found towards the "right hand" of scale, 1=worst, 7=best
- B-type scale where better values are found towards centre of scale, 4=best
- C-type scale where better values are found towards the “left hand” of scale, 1=best, 7=worst.

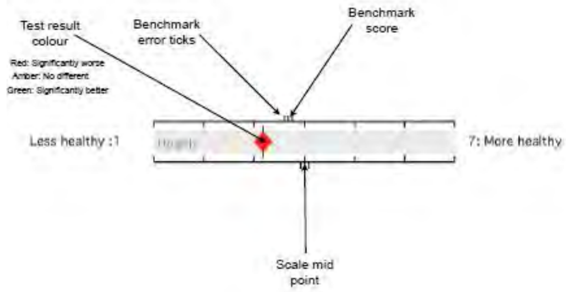

Figure 2. Key to BUS summary charts

The mean value from the survey is assessed against upper and lower limits from the benchmarks for both the benchmark value itself and the scale midpoint. The upper and lower limits are based on 95% confidence level. This creates the criteria for the green, amber or red results for the test as follows: Red diamonds are mean values significantly worse or lower than benchmark and scale midpoint (a poor score). Amber circles represents mean values no different, green squares are mean values significantly better or higher than both benchmark and scale midpoint (a good score). Benchmarks are represented by the three lines on the top scale of each variable and scale midpoint is represented on the bottom as shown in Figure 2 .

A total of 200 surveys were distributed and the respondents were faculty members and under-graduate students totalling 110 individuals whose age ranges from 18 to 45 years. The average weight is 61 kg, average height 1.64 m, 40% males and 60% females. As seen in Figure 3, overall ratings of temperature in summer are significantly lower than the

Midpoint and benchmarks for the case study building (Mean= 2.56, benchmark= 4.58; A type scale).The percentage of dissatisfaction during summer is 80% as per the results and is marked by red diamond in the Figure 2.

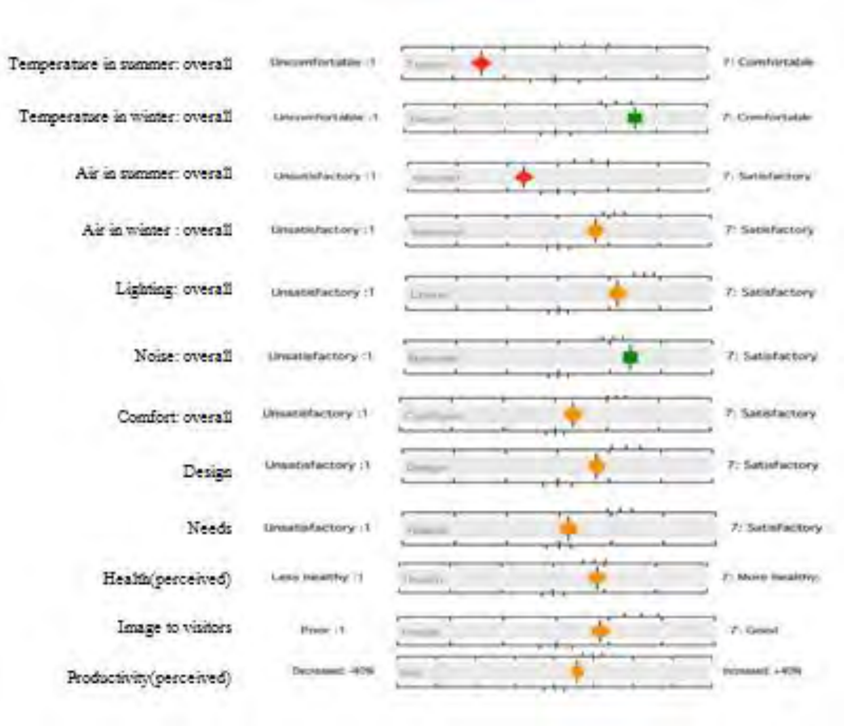

Figure 3. BUS summary chart for case study building.

Computational analysis

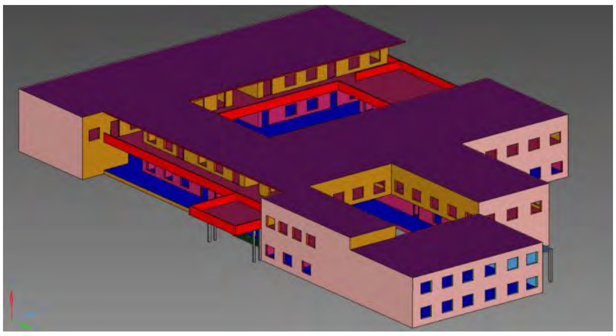

Figure 4. 3D model of the Institutional building for present investigation

The three- dimensional (3D) model of the building (Figure 4) was generated using Autodesk Rivet software and used for CFD analysis. The overall dimensions (Length L, Breadth B and Height H) of the building are 72 m, 44 m and 10 m respectively. The numerical simulation on the discretized domain is carried out using ANSYS Fluent. Standard k-Epsilon turbulence model is used to predict the turbulence and viscous effects. Sufficiently larger flow domain around the building is considered to capture proper building aerodynamics and ventilation. The physical model along with boundary domain is shown in Figure 5.

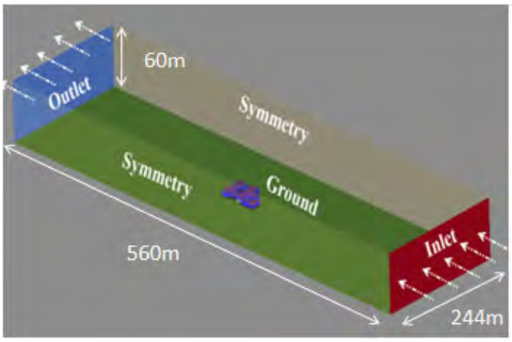

Figure 5. Physical model of the building inside the domain

Figure 6. a. Mesh refinement near the building and portico region, b. Surface mesh refinement near the opened windows

Table 1: Mesh details considered for the present analysis

S.no	Detail	Type	Quality	Count
1	Surface	Tria Elements	Skewness < 60	1.9 Millions
2	Volume	Tetra Elements	Tet Collapse < 0.1	7.4 Millions
3	Nodes	-----------	----------	1.7 Millions

A velocity specified domain inlet is used to indicate the air flow direction and speed. From the recorded outdoor weather data of Madurai, the lowest wind speed of 1km/hr blowing at angle of 254^0 N (southwest direction) and temperature of 37.9^{0}C at 2.30pm on March 24, 2016 was used to calculate the turbulence dissipation rate profiles at the inlet of the simulation domain. The reason for the choosing the data at the above mentioned particular timings was based on considering the BUS survey comments in which the occupants had mentioned that they felt more thermal discomfort during afternoon hours. The pressure is taken as 1.01325 bar. The sides of the flow domain are mentioned with 'symmetry' boundary condition (Fig.5). The building surfaces and ground are given with 'standard wall' boundary conditions. The domain outlet is set with 'pressure outlet' boundary condition. The constant static pressure boundary condition was used at the outlet of the calculation region (Yang et.al, 2014). A boundary domain of 560 m length, 244 m breadth and 60 m height has been selected and the fluid volume is discretized with tetra elements. To solve the governing equations of fluid flow over and through the institutional building, ANSYS Fluent is used. The solver solves Pressure Based Navier Stokes Equations (PBNS) along with turbulence (Jin et.al, 2013, Yang et.al, 2014).

In the present investigation the flow analysis is carried out by considering opened window condition so that the ventilation and airing performance inside the class rooms can be analyzed. The institutional building model is meshed with unstructured triangular elements. A growth rate of 1.9 million has been specified for tria mesh generation from building wall surfaces to the domain. Mesh refinement is given at appropriate locations of the building especially at flow entry zones like windows, doors, etc. Figure 6a depicts the surface mesh and its refinement near the building. Figure 6b shows the surface mesh refinement near the opened-windows and verandas. The overall mesh count created for the present analysis is around 8 millions (Table 1). Unstructured tetrahedral meshes of 7.4 million elements are created around the building. The total number of nodes taken for the computations is around 1.7 millions. The convergence of the solutions is set to 1*e-04. The simulation was carried out in a workstation with xenon processor and 32 GB Ram and it took nearly 72 hours to complete a simulation.

Results and Discussions

As the wind flow direction is from south west with a low speed of 1 km/hr, the pressure rise over the building is not much significant. Figure 7a shows the wind direction and Figure 7b the pressure rise over the rear surfaces of institutional building. It is observed from the numerical simulation that the wake formation in front the building is in cross wise direction as the flow strike angle is inclined to vertical axis of the building in south west direction. This is clearly predicted by the solver as the wake tends towards north east direction (Figure 8). Figure 9a and 9b demonstrates the air flow pattern in the ground floor and first floor. It can be visualized that low wind speed areas (low flow velocities under 0.5 m/s) appeared in most locations due to orientation of windows. The front façade of the building faces east and hence windows facing the east were mostly shaded with corridors as seen in Figure 9a. But some rooms especially on the north western part of the building have windows facing north, west and east. It shows cross ventilation of high velocity air through windows facing west into the studios (Figure 9a & 9b). Since there are no shading devices on the western part of the building, the air entering inside the building will definitely be very hot causing discomfort to the occupants. The simulation results showed variations in the movement of wind in the ground and first floor. Figure 9a and 9b represents the CFD simulation results of velocity magnitude of the ground floor and first floor respectively. It can be observed from the figures that high flow velocity vectors entering the building through windows facing west. Figure 9a represents the velocity magnitude streamlines of the ground floor plan and 9b shows the enlarged view of air flow pattern on the western part of the building.

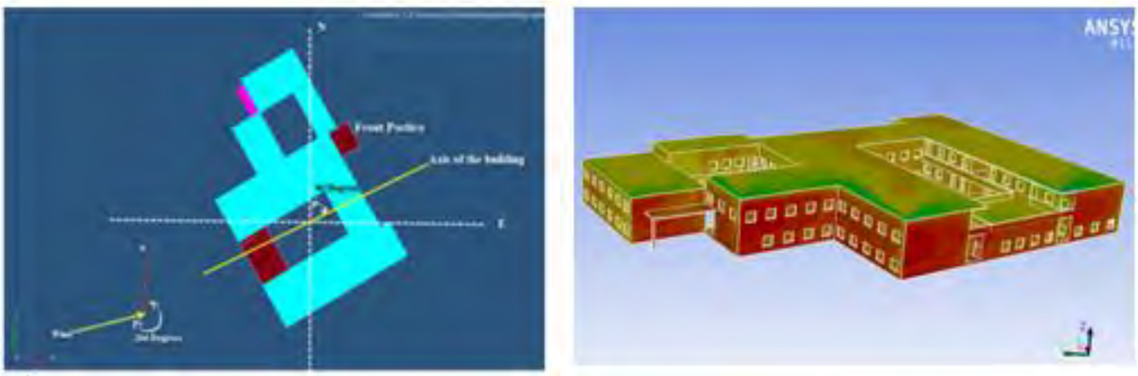

Figure 7.a. Wind Flow Direction for present numerical simulation, b. Static Pressure distribution over the building

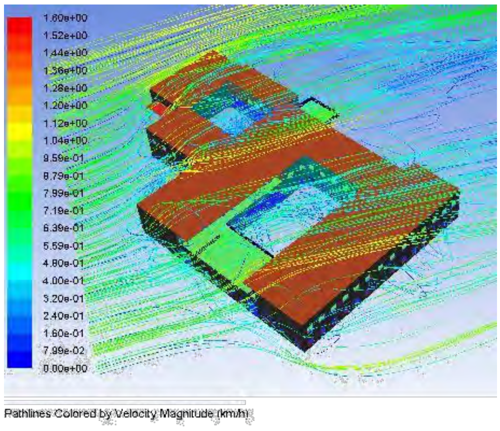

Figure 8. Wake formation and flow pattern around the building

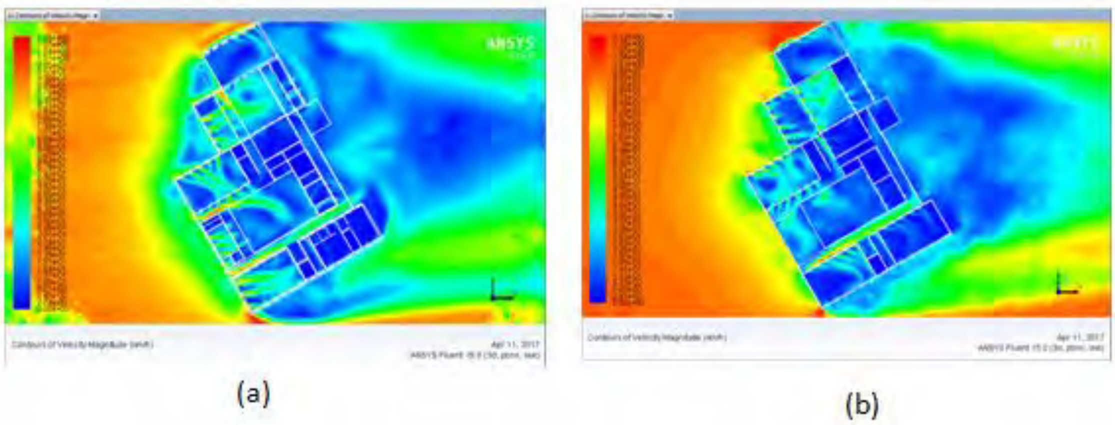

Figure 9. Predicted velocity magnitude contours in horizontal planes at ground floor and first floor level.

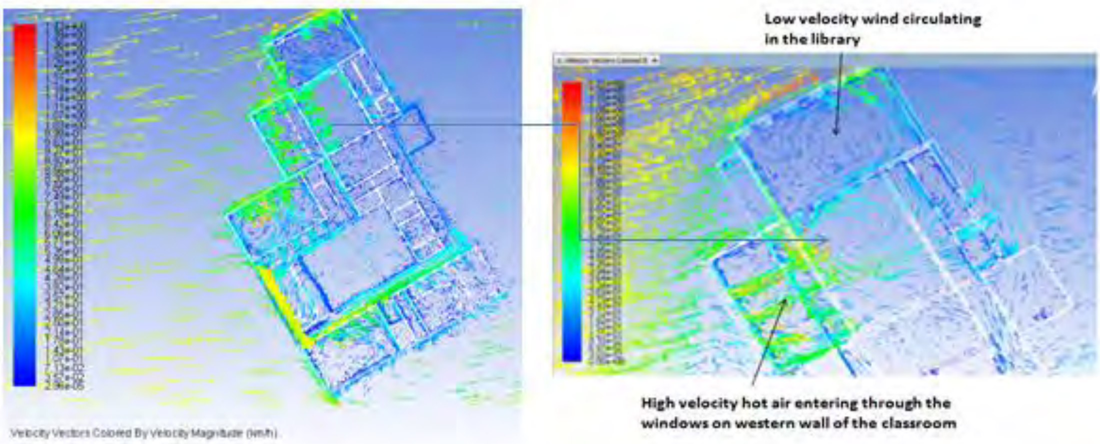

Figure 10. Air flow pattern inside the building at ground floor

Conclusion

In this study, natural ventilation has been investigated using CFD simulation techniques for a low-rise educational building in Madurai. The occupant comfort survey shows that occupants in the building were satisfied with the facilities and building design, except for heat in summer. The simulation results also showed variation in air circulation in the studios and classrooms. Based on the results it showed that a strong movement of air in the north western part of the building, as the plan is staggered with linear walls facing the west. Thus there is possibility of hot air movement from the windows facing west causing thermal discomfort to the occupants. There are also places where weaker recirculation is formed both in ground floor and first floor. Thus the computer results of the airflow properties were very helpful to form a digitized database system for future reference and also to understand the interaction between the building structures and the outdoor wind environment, thereby creating an opportunity to optimize the building envelope design for better thermal performance.

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Effectiveness of Natural and Mechanical *Ventilative Cooling* in Residential Building in Hot & Dry and Temperate Climate of India

Devna Vyas[1] and Michael Apte[1]

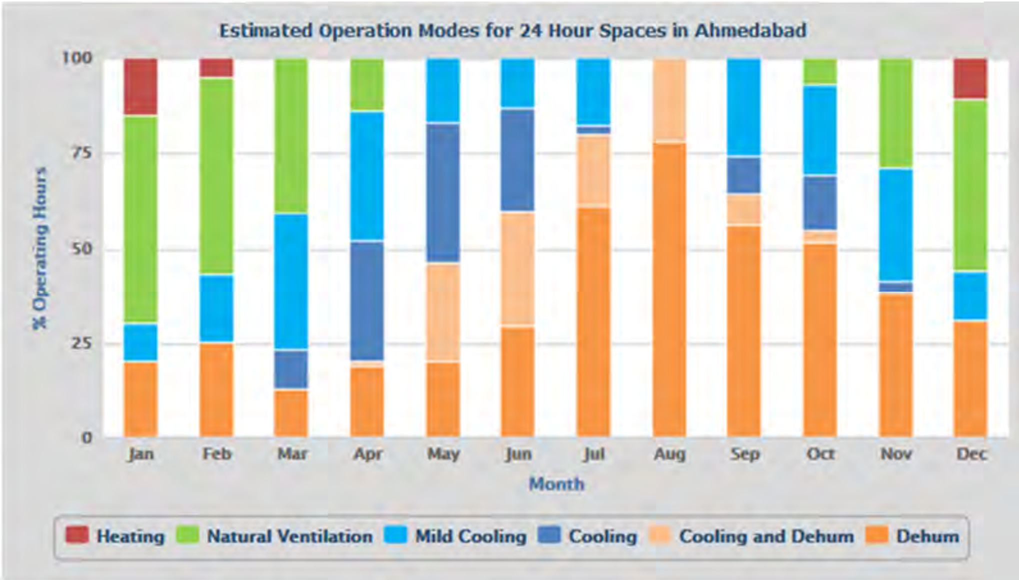
[1] Faculty of Technology, CEPT University, Ahmedabad, India
Correspondence email devna.vyas@gmail.com

Abstract: A residential energy consumption survey of India shows that just 2% of Indian households had air-conditioning in 2007. However, the situation is changing rapidly and the purchase of air-conditioners is showing 20% increase in sales annually. The potential for ventilative cooling to address, in part, these cooling needs has not been sufficiently researched in Indian context and demands immediate attention. This study evaluates the benefit of ventilative cooling techniques in Indian residences. The study first identifies typical single-bedroom apartment plans in multi-family building in India based on past studies and literature. These plans are simulated in DesignBuilder and EnergyPlus simulation models to understand baseline energy consumption. Further, three ventilative cooling design strategies (single-sided natural ventilation, cross-flow natural ventilation, and fan-assisted mechanical ventilation) are designed and incorporated in the residential plans to assess the ventilative cooling benefits. The effectiveness of ventilative cooling is investigated for two representative cities (Ahmedabad, hot and dry; Bangalore, temperate) located in two different climate zones of India. The simulated ventilative cooling benefits are quantified by reduction in cooling hours, reduction in annual and seasonal cooling loads, and reduction in energy use. Further, an hourly heat map for each residence type, for base case (without ventilative cooling), and for various natural and mechanical ventilative cooling strategies, is also prepared for granular comparison. Short-term field measurements of key environmental and building parameters (such as ventilation rates and heat transfer) is conducted in an apartment building to validate key simulation input assumptions. These measurements, supported by physical models, is used to calculate time-averaged ventilative cooling rates. The study provides scientific basis to building designers in understanding the benefits and limitations of natural and mechanical ventilative cooling in Indian residences.

Keywords: Ventilative Cooling, Residential, Natural Ventilation, Mechanical Ventilation, Building Simulation

Introduction

Increasing income and the preference of comfort conditions in India has led to a rapid increase in energy demand for space cooling (Rawal & Shukla 2014). Currently, there are very few residences where mechanical cooling is used; most of the population of India relies on natural, fan-assisted, or evaporative cooling. A residential energy consumption survey of India shows that just 2% of Indian households had air-conditioning in 2007 (McNeil & Letschert 2010). However, the situation is changing and the purchase of air-conditioners is most prevalent in middle class, showing a 20% increase in sales annually (McNeil & Letschert 2010). The potential of cooling with natural ventilation and forced ventilation demands attention and scientific study in order to 1) cater to the need of the larger portion of the population; those who cannot afford air-conditioning and 2) in order to reduce India's energy consumption and reduce its greenhouse gas emissions due to space cooling demands.



Source: (Center for Advanced Research in Building Science and Energy 2016)
Figure 1. Estimated Operation Models for 24 Hour Space in Ahmedabad

Ventilative cooling refers to the use of natural or mechanical ventilation strategies to cool indoor spaces using outdoor air. The most common ventilative cooling technique is the use of increased ventilation airflow rates during cooler outdoor periods, and night ventilation, but other technologies may also be considered. Effectiveness of ventilative cooling is dependent on the availability of suitable ambient conditions to provide cooling to the space. Figure 1 shows estimated operation modes for 24 hour spaces in Ahmedabad based on outdoor climate analysis (Center for Advanced Research in Building Science and Energy 2016). The figure shows that natural ventilation is plausible for seven months (7) of the year for twenty-four (24) hour spaces located in Ahmedabad with November to March period most suitable for ventilative cooling. However, the net benefit of ventilative cooling depends on several factors such as building thermal characteristics, cooling needs, and comfort requirements of the space. This study evaluates the benefit of harnessing cooler ambient air to enhance indoor temperatures without resorting to more energy intensive methods such as air conditioning.

Brief Literature Review

Literature review has been divided in two areas: literature that guide on principles and design of natural and mechanical ventilative cooling, and literature that assess the benefits of ventilative cooling. Engel provides detailed theory of natural and mechanical ventilation based on sun, wind, and buoyancy (Engel et al. 2012) and claims that hybrid ventilation reduces energy consumption of the building for same thermal comfort criteria while also improving indoor air quality. Axley provides a detailed methodology to use natural and hybrid ventilation to cool buildings (Axley et al. 2002) by suggesting three steps to design ventilation system for cooling – suitability analysis, loop equation design method to size ventilation system components and control strategies, and multi-zone coupled thermal- airflow analysis for design development and performance analysis of ventilation system. Similarly, Heiselberg (Heiselberg 2002) and Jicha (Jicha & Charvat 2007) provide detailed overview of hybrid ventilation types, advantages and disadvantages of hybrid ventilation, design tools, examples, and maintenance requirements. IEA-Annex 62 (Kolokotroni & Heiselberg 2015) provide thorough overview of ventilative cooling strategies with detailed description of sizing tools and techniques. The principles, tools, and equations provided have been used as a basis for designing components of ventilative cooling system for typical residential buildings in India.

Salcido conducted extensive literature review of the work conducted in mixed mode ventilation (MMV) area in the past two decades (1996-2016) (Salcido et al. 2016). The study highlighted that up to 40% of HVAC energy consumption can be reduced with natural ventilation in non-residential buildings through window optimization designs and schedules. Liping (Liping & Hien 2007) assessed effectiveness of four ventilation strategies – night time ventilation, day time ventilation, full day ventilation, and no ventilation – in residences located in hot and humid climates. Similarly, Albadra (Albadra & Lo 2014) have carried out a study to quantify the limits of outdoor environmental conditions under which natural (day and night time) ventilation is an effective strategy for achieving thermal comfort along with exploring the effects of certain building characteristics. Aflaki (Aflaki et al. 2016) studied the impact of natural ventilation on thermal performance of a high-rise residential building and advocated use of single side ventilation strategies in residential building.

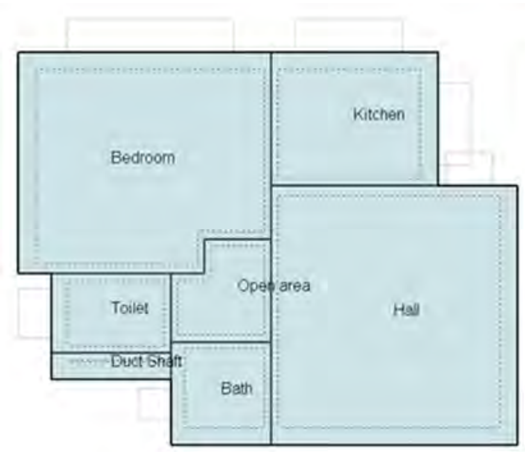
Fu assessed efficiency of hybrid ventilation modes for using two different thermal comfort models - predicted mean vote (PMV) and adaptive thermal comfort model (ACS) (Fu & Wu 2015) and suggested adaptive comfort model as more suitable for ventilation model. Adaptive comfort model proposed in ASHRAE 55 is limited to naturally ventilated building. Manu (Manu et al. 2016) developed adaptive comfort model suitable for mixed mode office buildings in India. This model for mixed mode building has also been adopted by National Building Code (NBC).

There are very few studies that have attempted to study free cooling benefit for buildings in India. Iddon demonstrated that night purge can provide 10% reduction in annual cooling load in an office building located in Pune (Iddon & ParasuRaman 2015). Similarly, Thambidurai (Thambidurai et al. 2015) studied free cooling feasibility of a typical commercial building in Pune and concluded that in a city like Pune with moderate climate free cooling with thermal storage can limit the use of air conditioning system only to three months (March, April, and May). Gradillas (Gradillas 2015) studied the benefits of natural ventilative cooling in hypothetical cube located in Bhuj, Gujarat using DesignBuilder for two design strategies (single-side ventilation and cross ventilation). While the study estimated positive benefits of ventilative cooling, the application of this study can be quite limited due to location specific climate and a small cube design. Thomas (Thomas & Thomas 2014) compares the benefits of natural ventilation in modern apartment buildings in Sydney, Australia and Bengaluru, India. The study concludes that significantly energy savings potential can be achieved if the apartments are designed or retrofitted as per natural ventilation guidelines and principles mentioned in the national building codes (NBC) and residential flat design code (RFDC). While the study provided suggestions on possible natural ventilation strategies for a residential plan and suggested good potential of the same based on climate analysis, it has not simulated or calculated benefits of the approach. No prior study was found that conducted detailed analysis of ventilative cooling benefits in Indian residences. Hence, this paper aims to conduct detailed investigation on cooling benefits of various (natural and mechanical) ventilative cooling strategies in Indian residences located in hot and dry and temperate climate of India.

Methodology

Overall, the study methodology is divided in two parts – simulation and field measurements. Thermal simulation is the primary focus of this paper and has been used to estimate benefits of ventilative cooling in a typical single-bedroom apartment in multi-family buildings. The field measurements are designed quantifying inputs and validating outputs of the simulation models using on-site measurements. Currently, there are no code requirements in India on ventilation or indoor air quality requirements for residences. Hence, benefits in indoor air quality due to natural and ventilation is not scope of this paper.

Typical configuration of individual apartment floor plans of residential buildings is extensively reviewed in two studies based on large number of surveys in India (BEEP 2016; Rawal & Shukla 2014). These studies have also suggested various simulation inputs for typical residential models including appliance penetration, occupancy schedule, and envelope construction for a typical multi-family residential building in India. The studies also highlight that the Indian residences are designed for zoned mixed mode where an air conditioning system is typically installed only in the bedrooms. Further, the air-conditioning system in the bedroom operates in change-over mixed mode where the system runs only during extreme weather periods. DesignBuilder uses EnergyPlus AIRNET method to calculate airflow rates from openings and assumes all openings to be vertical. A model of a single bedroom apartment was created in DesignBuilder to estimate benefits of ventilative cooling. Figure 2 shows building plan in DesignBuilder and key simulation inputs used in thermal simulation model:



Envelope Construction and Thermal Properties	
Wall	12mm Outside Plaster + 230 mm brick wall + 12 mm Inside Plaster U-Value - 1.722 W/m2-K
Roof	10 mm Tiles + 12mm Plaster + 150 mm concrete roof + 12mm Plaster U-Value - 2.942 W/m2-K
Window	Single Glazing with Aluminium Frame 22% Window to Wall Ratio (as per plan) U-Value - 5.8 W/m2-K, SHGC - 0.82, VLT – 0.8
Floor	10 mm Tiles +12mm Plaster + 150 mm concrete roof + 12mm Plaster U-Value - 2.942 W/m2-K
Zone Area, Operation Schedule, Occupancy and Internal Heat Gains	
Bedroom	Operation: 10 pm to 7 am, Internal Gains (lighting + equipment): 320 Watts, Occupancy: 2 people, Area: 9.6 m2
Living Area / Kitchen / Others	Operation: 7 am to 10 am and 7 pm – 10 pm, Internal Gains (lighting + equipment): 800 Watts, Occupancy: 2 people, Area: 20.4 m2

Figure 2. Single-bedroom Apartment Plan and Thermal Simulation Inputs

Figure 3 shows simulation run chart containing forty simulations per each climate zone where impact of climate zones, orientation, and ventilation strategies has been assessed against a reference case. Ahmedabad (located in hot and dry climate) and Bangalore (temperate climate) has been selected as a representative city for hot and dry as well as temperate climate. Since IMAC comfort model is specifically developed for mixed mode buildings (Manu et al. 2016), and considering lack of alternative models that can be applied to residences in India, the adaptive thermal comfort model has been applied to assess comfort and to determine cooling needs.

In parallel, ventilation rates under no ventilation, natural ventilation, and mechanical ventilation strategies is measured in one bedroom of an unoccupied two-bedroom apartment. For continuous ventilation measurements in the apartment, a novel tracer gas method was developed and tested for cost-effective yet real time air exchange rate measurements. In this method, a block (approximately 10 kg) of dry ice is placed in an insulated cooler on a precision weighing scale inside the space and allowed to slowly release carbon dioxide (CO_2) in the space at a measured rate. Concurrently, a calibrated CO_2 sensor continuously measures CO_2 levels in the space. Using mass conservation, the ventilation rates are continuously calculated for each measurement period. These field measurements are not aimed to provide thorough validation or to calibrate simulation models but to derive realistic input assumptions.

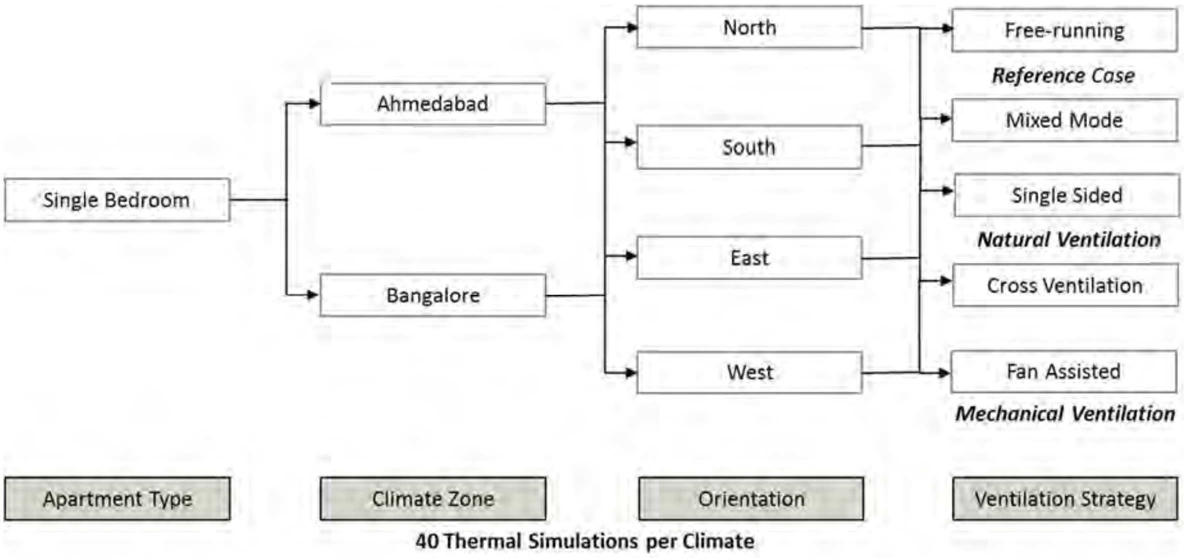


Figure 3. Simulation Run Chart

Sizing of Ventilation Components

Natural ventilation opening and mechanical fan flow rates for one bedroom apartment were determined in three steps: (1) calculate the period when ventilative cooling could be useful, (2) calculate flow rate requirements for the space, and (3) size opening and mechanical fan flow. To determine period when ventilative cooling can be useful, thermal simulation of the above described prototypical one bedroom apartment is run in the free-running mode. The space operative temperature (OT), which is arithmetic mean of air temperature and mean radiant temperature, from the simulation is compared against the adaptive setpoint (AS) and outdoor temperatures (OAT) to determine the period when ventilative cooling can be useful. Based on the comparison, Figure 4 shows when the outdoor temperature is too cold (blue), is beneficial for ventilative cooling (green), and is too hot (Red).

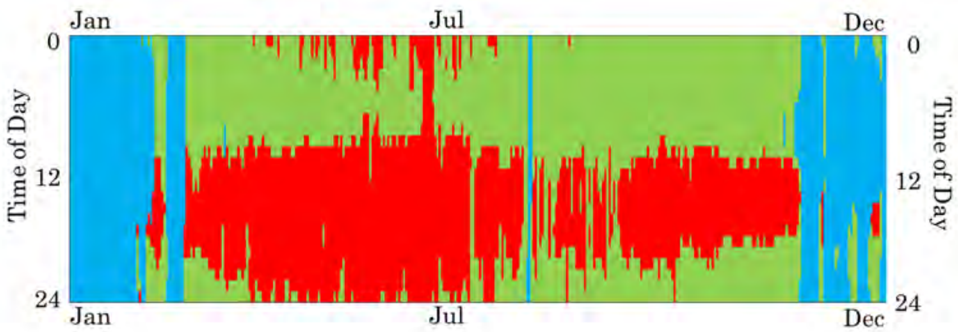


Figure 4. Simulation of 1BHK Residential Apartment in Free Running Mode to Determine Building Operative Temperature – North Orientation in Ahmedabad

Ideal flow rate for the ventilative cooling is calculated for each hour using the following method:

$$Air\ Change\ per\ Hour\ (ACH) = \frac{Flow\ Rate}{Volume} = \frac{1}{V_{room}} \times \frac{[\rho_{air} V_{room} C_p (T_{room} - T_{setpoint}) + Q_{internal}]}{\rho_{air} C_p (T_{room} - T_{outdoor})}$$

Where, ρ_{air} is density of air, C_p is specific heat of air, V_{room} is space volume, T_{room} is room temperature, $T_{setpoint}$ is setpoint derived from IMAC adaptive comfort equation (Manu et al. 2016), $T_{outdoor}$ is outdoor air temperature, and $Q_{internal}$ is internal heat gain. A flow rate of 3 air change per hour (ACH) was found to meet ideal flow requirements for 88% of the hours when ventilative cooling is useful. Hence, mechanical fan for bedroom (of 30 m^3 volume) is designed to provide 90 m^3/hour for ventilative cooling. The fan is turned on only during the period when ventilative cooling is effective. Following equation is used to determine natural ventilation opening size for each hour:

$$A = \frac{q}{C_d} \times \sqrt{\frac{\rho}{2\Delta P}}$$

Where, ρ_{air} is density of air, C_d is coefficient of discharge (0.61), q is ideal flow rate, and ΔP is pressure difference across opening (due to wind and stack). Using above equation, ideal effective opening area is calculated for every hour throughout the year (similar to ideal flow requirement). Wind velocity and direction is obtained from TMY3 weather file for Ahmedabad and Bangalore. Based on the analysis, an opening area of 0.5 m^2 in Ahmedabad and 0.4 m^2 in Bangalore could meet ideal flow requirements for 85% of the hours when ventilative cooling is useful. Opening area is added in the simulation model to determine ventilative cooling benefits.

Results and Discussions

The simulation results are compared using two metrics – uncomfortable hours and reduction in thermal cooling needs of the space. The operative temperatures from simulation results are extracted and compared with the IMAC adaptive comfort setpoints (Manu et al. 2016) to determine the uncomfortable hours for free-running mode and for each ventilative cooling strategies. To determine reduction in cooling thermal needs, the annual delivered system cooling is extracted from the simulation models for mixed mode operation and each of the ventilation cooling strategies. Figure 6 shows summary results for reduction in uncomfortable hours and thermal cooling needs of the space.

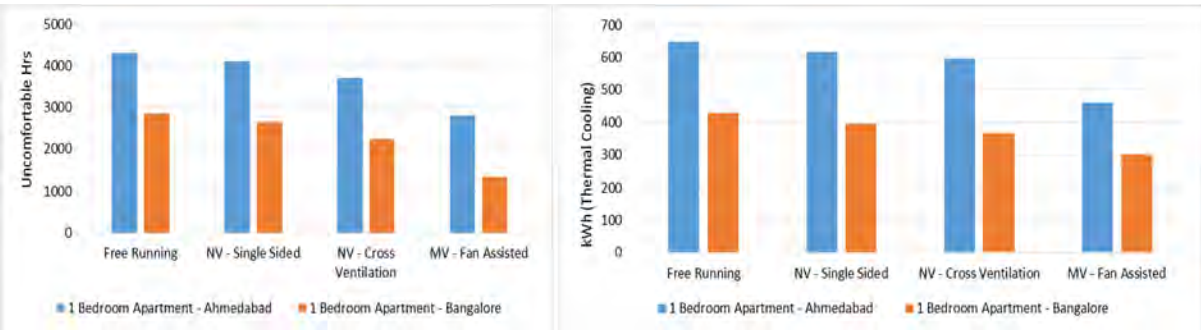


Figure 5. Annual Ventilative Cooling Benefits for Ahmedabad and Bangalore

Calculating from data shown in Figure 6, natural (NV) and mechanical ventilation (MV) can reduce uncomfortable hours by 10-12% and 21-40%, respectively, as compared to free-running mode. Similarly, natural and mechanical ventilation can reduce thermal cooling needs of the space by 12-14% and 30-35%, respectively, as compared to mixed mode operation. The ventilative cooling benefits are 2-10% higher in temperate climate as compared with hot and dry climate. Further, the orientation plays important role for natural ventilation savings but have marginal impact on savings due to mechanical ventilation. The ventilative cooling benefits are slightly higher (3-5%) for cross-ventilation as compared to the single-sided ventilation.

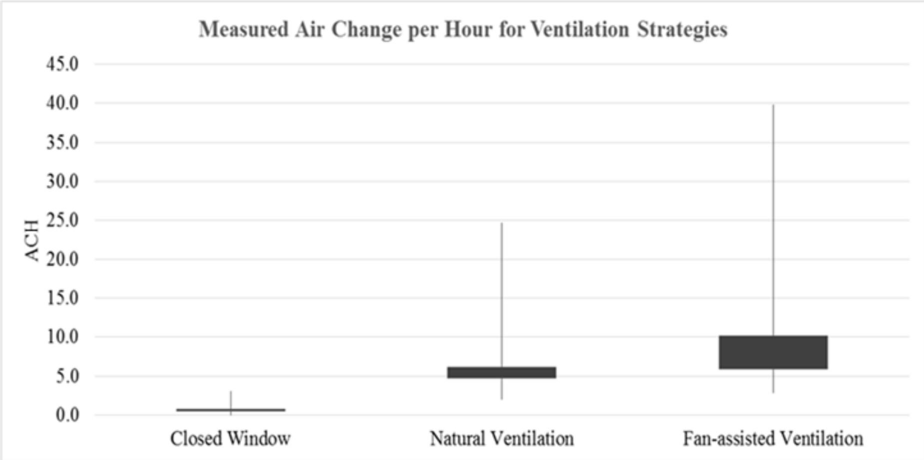


Figure 6. Field Ventilation Measurements for Ventilation Strategies

The measurements were conducted for a period of 30 days in the month of March and April. Data were recorded for three modes; free running, natural ventilation, and mechanical (fan-assisted) ventilation in random order during the course of measurement period. Figure 7 shows measured ventilation measurements in the apartment building for three ventilation strategies.

The closed window mode where there is no natural ventilation happening, the air change as a result of infiltration shows the values of 0 - 2 ACH with the average value of 1 ACH. In the natural ventilation mode when the windows are open from morning to evening, the ACH values varies between 2.5 to 25 ACH and the average value is observed to be 6 ACH. For the fan-assisted mode, where a fan is kept on inside of the open window, the ACH values vary between 3 ACH to 40 ACH sometimes with an average value observed to be around 8 ACH. The variation in measured ventilation rate is high for natural and mechanical ventilation strategies and need further investigation on the causes of the variation.

Conclusions

The results demonstrate the potential for natural and mechanical ventilation strategies to be effective for single-bedroom residences in India providing 10-14% reduction in uncomfortable hours and 21-40% reduction in annual cooling needs. While ventilative cooling is more effective in temperate climate, significant benefits can be achieved even in hot and dry climate of India during night periods.
A novel method to continuously measure ventilation rate is developed for affordable yet accurate measurements. Short-term field measurements (of 30 days) showed that no ventilation, natural ventilation, and mechanical ventilation yields 1 ACH, 6 ACH, and 8 ACH, respectively. Future research will include more field measurements, different typology of apartments (2 bedroom and 3 bedroom), granular analysis of benefits, and more ventilation strategies (stack ventilation at building level). Further improvement in method can increase robustness of the method.

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Design to Thrive

Winter Indoor thermal environment investigation in apartments at a central China city and Dutch Eindhoven

Yin Wei[1,2] , Jie Han[1], Hui Chen[1], Guoqiang Zhang[1], Zhaonan Xu[1]

[1] College of Architecture, Hunan University, Changsha, Hunan 410082, China
[2] School of Civil Engineering, Hunan University of Science and technology, Xiangtan, Hunan, China

Abstract: This paper intends to use an example to reveal some realities of indoor thermal environment in residential building of central China, and compare that with Europe. People living in the Humid Subtropical Climate of central China often complain of the cold indoor environment during the winter, despite their use of heating appliances. To address this issue, this study conducted an investigation on two indoor thermal environments during the equivalent-time periods. The first in a typical apartment in Xiangtan, a city of central China, and the second in the city of Eindhoven, which is located in southern Netherlands. The former was conducted from November to January, and the latter was from February to March. It was found that the indoor temperature of the apartment in China was between 14-20°C, in comparison to 20-24°C in the apartment of Eindhoven. In addition, the apartment located in Eindhoven yielded larger differences between the moisture content inside the building and outdoor environment, indicating that the building was better air-tight than Xiangtan's. This is a common problem with residential buildings in this location in China. An air-tight building is required for heat-isolation, and is a suitable direction to take when retrofitting existing residential buildings to obtain better indoor environment in this climate zone. Furthermore, the indoor thermal situation representative in this climate zone of China might not be in the range suitable for adaptive thermal comfort.

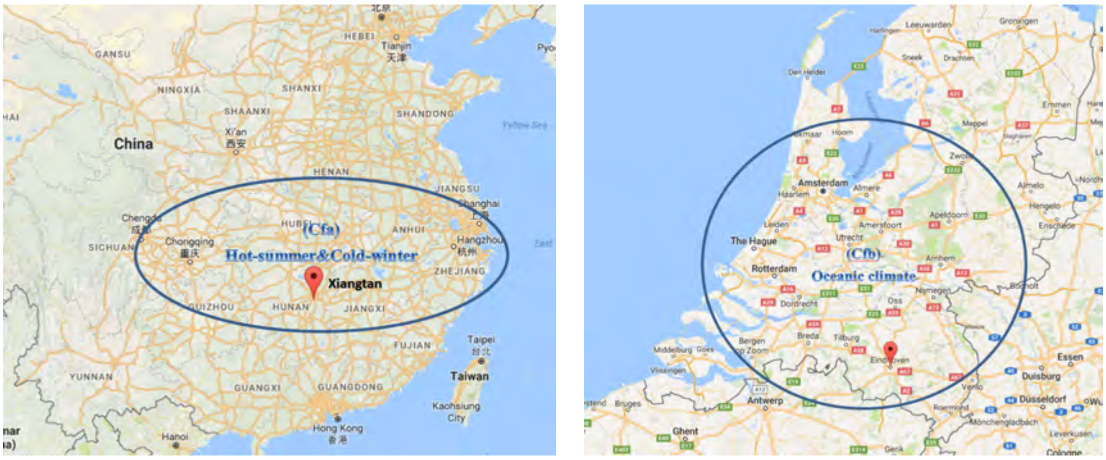
Keywords: Winter indoor environment, thermal comfort, hot-summer and cold-winter (Humid Subtropical Climate), residential buildings retrofitted, difference between Europe and China

Introduction

Indoor thermal environment during the winter is a significant factor to occupants' health and thermal comfort. Although it seems a traditional topic, many buildings in China and across the world still suffer from the issue of unsuitable indoor temperature in residential buildings.

Kuchen, E. and M. N. Fisch (2009) surveyed the thermal comfort of the occupants in 25 office buildings during the winter in Germany, with measured data and the subjective data, by which it was found that the persons can accept a neutral temperature near the imposed pre-established value of the operative temperature. Zeiler, W. and G. Boxem (2009) focused on the thermal comfort of the schools in the Netherlands via measurements and questionnaires held in 14 schools, equipped with different types of ventilation and heating systems. It was found that Thermo-Active Building Systems, an new systems combined with natural air supply and mechanical exhaust, could produce a small improvement of perceived thermal comfort at school buildings in winter. Kavgic, M., et al. (2012) investigated winter indoor temperatures, relative humidity and vapour pressure across 96 representative dwellings at Belgrade in southern Europe. It was found that district heating produced a high degree of overheating, which is an issue for future work to solve to increase the energy efficiency of buildings. Luo, M., et al. (2014) investigated 139 residential apartments in Beijing and Shanghai, and found that occupants with the capability of individual control over space heating systems had a 2.6 °C lower neutral temperature than those without personal control. Yu, Z., et al. (2015) recommended that the temperature range for temporarily occupied space, such as supermarkets, to be 16.9 °C -17.4 °C at Tianjing near Beijing, in the cold climate region of China, based on results of experiment in a climate chamber.

China’s central zone is located in the climate area named hot-summer and cold-winter climate zone(HSCW), which is defined as Humid Subtropical Climate (marked as Cfa) in Köppen-Geigers system of climate classification, shown in in Figure 1a. More than 400 million people, one-third of Chinese nationality, live in the region shown in blue circle in Figure 1b. The average temperature in winter is around 5 °C, which is much higher than northern China. However, occupants living in the specified region complain of the cold during the winter, even though there are heating supplied by air-heat-pump from air-conditioning systems.



(a) (b)

Figure 1. Climate regions where two cities located.

Some research has been conducted to shed further light on the winter indoor thermal comfort in the Humid Subtropical Climate region of China. Lin, B., et al. (2016) found that the average internal temperature in the HSCW region of China is 13.5 °C for the living room, and 12.7 °C for the bedroom, producing an uncomfortable indoor thermal environment, markedly colder than that in the UK as similar winter climate, who experience temperatures of 19 °C. Cao, B., et al. (2016) conducted a comparative winter thermal comfort field study in Harbin(46deg.NL), Beijing(40deg.NL) and Shanghai(31deg.NL), which represented the Severe Cold zone, Cold zone, and Hot Summer & Cold Winter zone respectively. It found that the indoor temperature in Shanghai exceeded 80% in the temperature range of 16–22 °C, which is lower than those experienced in Harbin and Beijing with district heating supplied indoors. In addition Shanghai’s percentage of acceptance is higher than Beijing but lower than Harbin.

Some work has been conducted to provide a comparison to indoor thermal comforts between China and Europe. Zhang, N., et al. (2018) compared winter indoor thermal environments in two northern cities, Beijing and Harbin, with other 8 cities from South Europe and North America, all in a similar latitude range. It was found that Chinese cities had a lower temperature than European and North American cities, and that their neutral temperatures were 21.7℃, 23.4 ℃ and 22.7 ℃ respectively [8].

Until now, there have been few research studies conducted comparing the indoor thermal environment of residential buildings during the winter, between central China and western Europe, in which climate found in the Netherlands represents a typical European climate marked as Cfb in Köppen-Geiger with warm, temperate and rainy weather, and its winter around 3 ℃, shown in Figure 1b. During the winter of 2016-2017, a family of 4 persons including the author moved from an apartment located at Xiangtan central China to Eindhoven southern Netherlands. All people in this family feel much more comfortable indoor climate in Eindhoven than Xiangtan, where even they had resided for 20 years. Similar equipment had been used to record the field data and find out the direct reason behind occupant discomfort.

Survey methodology

An investigation was undertaken from Nov. 27 of 2016 to Jan. 9 of 2017 at a Xiangtan's apartment located on the 6th floor of a residential building (7 storeys high), which was built in 2005. A second survey was employed from Feb. 8 to Mar. 12 of 2017 in a second-floor apartment at a building more than 80 years old in Eindhoven, but retrofitted in (year) to include an individual central gas-heating system. Both of them represent their local indoor thermal environment individually.

In Xiangtan's apartments, a Logger was recording temperature and relative humidity placed outside the south window with a recording interval rate of five-minutes, depicted in Figure 2. Then the same Logger was used in Eindhoven, from Feb. to Mar. of 2017. Thus, some of following figures show the data of difference cities at one successive profile, in which the early part is the China and the later part is Eindhoven. So do another Logger in bedroom.

Xiangtan Eindhoven

Figure 2. Apartments at central China and northern Netherland.

It needs to be highlighted that during daytime when the recording equipment was placed on the windowsill, it was recording partly the operative temperature combining air dry-bulb temperature and solar radiation due to its direct exposure to the sunlight. The diversity between outdoor operative temperature and dry-bulb temperature was analysed as part of the daily analysis, in which outdoor dry-bulb temperature was acquired from the online weather data of the Weather Company (2017).

Data analysis

Winter outdoor climate

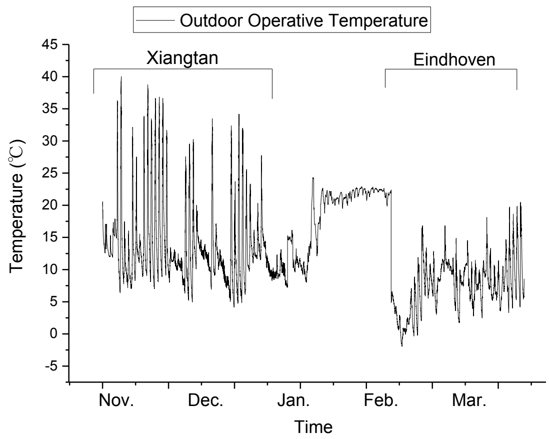


Figure 3. Outdoor operative temperatures at Xiangtan of China and Eindhoven of Netherlands.

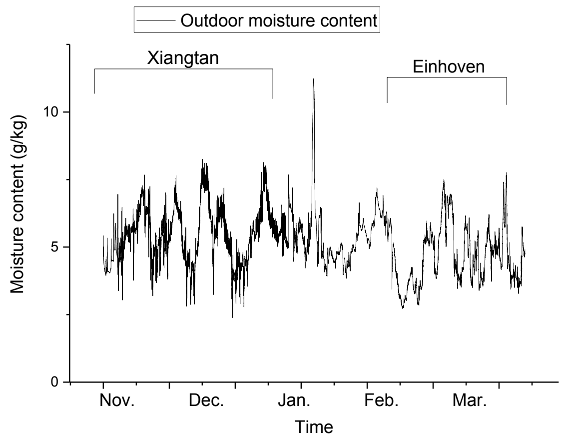


Figure 4. Outdoor moisture content at two cities.

As calculated from the field data, the neutral indoor operative temperature during the winter in Xiangtan was 13.2 °C, and 7.6 °C in Eindhoven, which indicates that Xiangtan has a warmer outdoor environment than Eindhoven. In Figure 3, it is illustrated that the amplitude of operative temperature fluctuation in Xiangtan was higher than in Eindhoven, as well as experiencing large fluctuations, which means the stronger solar radiation is occurring in central China than in the southern Netherlands.

In figure 4 the outdoor moisture content calculated from temperature and relative humidity is provided. The left and right elements of the moisture content profile in figure 4 revealed similar shapes and levels in both Xiangtan and Eindhoven, with a mean moisture content 5.5g/kg and 4.7 g/kg respectively.

Indoor thermal environment

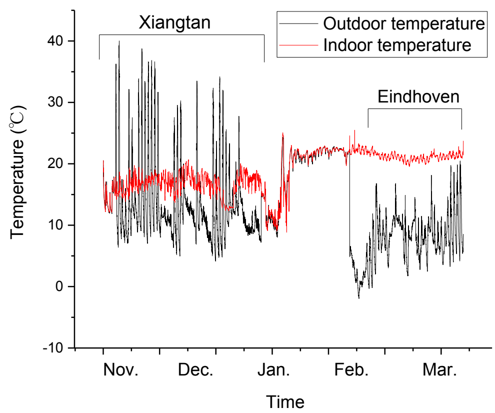


Figure 5. Indoor dry-bulb temperature.

In bedroom of apartment at Xiangtan, air-heat-pump heating from air-conditioning system was working during most of winter occupant time. At Eindhoven the central gas-heating system was working whole day. Figure 5 indicates that the indoor temperature is under 20 °C during most of time in China, in comparison to above 20 °C in Dutch.

Indoor temperature is more fluctuant in Xiangtan. On the one hand, the variance of Xiangtan's data is 2.8, and Eindhoven is only 0.4. On the second hand, figure 6 illustrated that Xiangtan's 91% temperatures are among 14 °C to 20 °C(23%+48%+19%)). Eindhoven's 97% temperatures are among 20°C to 24 °C, in which 20°C to 22 °C occupies 89%.

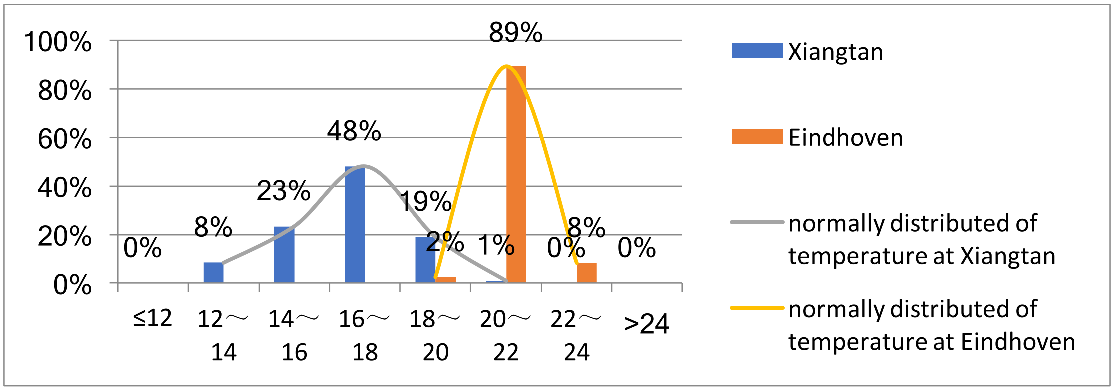


Figure 6. Distribution of indoor temperature.

The lower and more unstable indoor temperature is not only due to underpowered heating supply, but also bad insulation and airtight. Although this is only a case study, it represents the typical phenomena of low temperature in this region of China. Therefore local people have to wear thick clothes to keep warn.

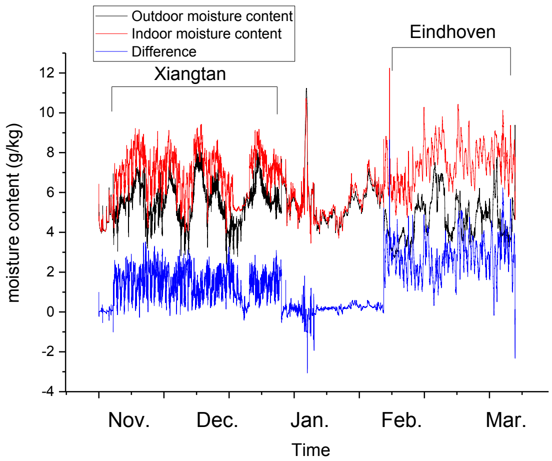


Figure 7. Indoor moisture content.

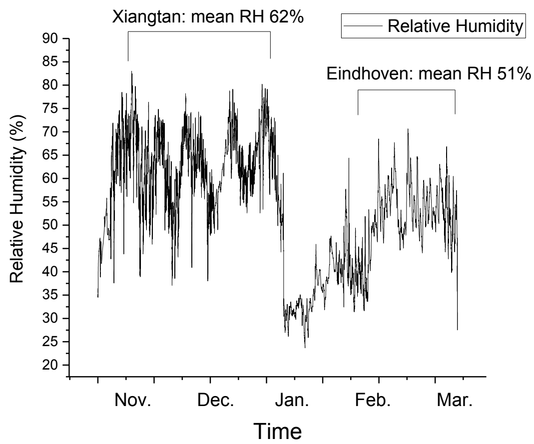


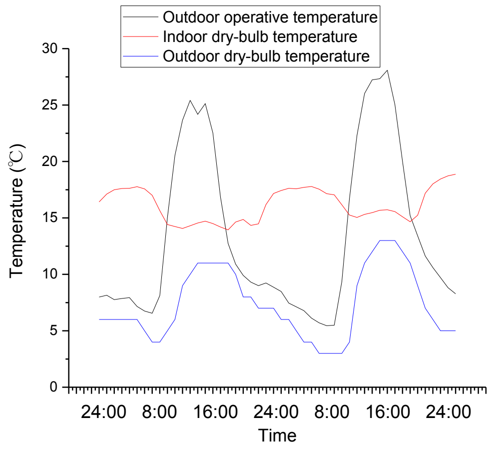
Figure 8. Indoor relative humidity

As shown as figure 7, the indoor moisture contents at Xiangtan are at approximate level as Eindhoven. From calculation, the mean value of the former is 6.9g/kg similar to the latter 7.5 g/kg, as well as former variance 1.11 to latter 1.04. Nonetheless the former is smaller at moisture content difference, between indoor and outsiders, at 1.4 g/kg, in comparison to the latter's 2.8 g/kg. It may be that the residential building in China has worse airtight. Because it needs much natural ventilation to dissipate heat during spring, summer and fall, there are cracks around windows and doors.

Figure 8 indicates that it is dryer in Eindhoven than Xiangtan, which might be a reason causing comfort feeling.

Daily change of indoor thermal environment

Typical daily indoor temperature



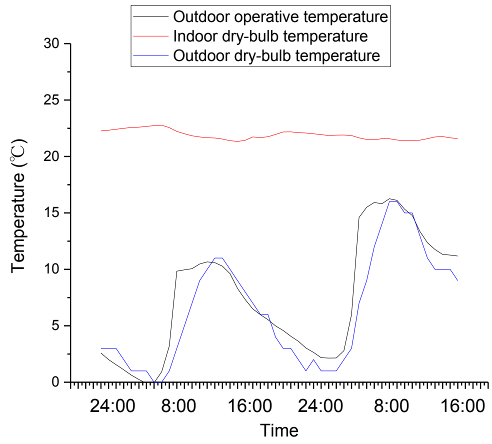


Figure 9(a). Indoor temperature during Dec. 15-16 of 2016 at Xiangtan.

Figure 9(b) Indoor temperature during Feb. 14-15 of 2017 at Eindhoven

Figure 9(a) draws the profiles of indoor dry-bulb temperature, outdoor operative temperature, and dry-bulb temperature, during two-day of Dec. 15-16 of 2016 at Xiangtan. 9(b) provides the same parameter during Feb. 14-15 of 2017 at Eindhoven. They were both sunny during these days.

Shown in Figure 9(a), the outdoor operative temperature is much higher than indoor dry-bulb temperature at most of daytime. However, it isn't happen at Eindhoven in Figure 9(b). Its outdoor operative temperature and dry-bulb temperature are very approximate hour by hour. This implies Xiangtan has stronger solar radiation than Eindhoven during the winter's sunny days.

It is observed that in Figure 9(a) that the profile of indoor temperature of daytime is a little bit lower than night-time. This is due to nobody home and heating system is not working.

According to statistics during two days, Xiangtan's indoor temperature varies from 13°C to 19 °C, nearly 6 Celsius gap. Eindhoven is at interval of 22 to 26 °C. Their average outdoor temperatures are 6.4 °C to 7.4 °C respectively. This is according with their trends of whole season data.

Daily indoor moisture content

In figure 10, the Eindhoven's curve has two peaks when the sleeping time. However Xiangtan's varies irregularly. In figure 11(a), the absolute humidity of indoor and outdoor during night-time seems having the similar trend. But in figure 11(b) there is less similarity of them. This as well could be proved from correlated coefficients between indoor and outdoor moisture content in Table 1, China 0.59 to Netherlands 0.37. It may mean that the Chinese resident building has worse airtight.

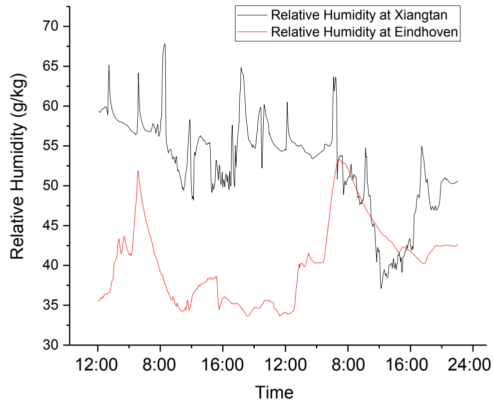


Figure 10. Indoor relative humidity of two days at Xiang and Eindhoven.

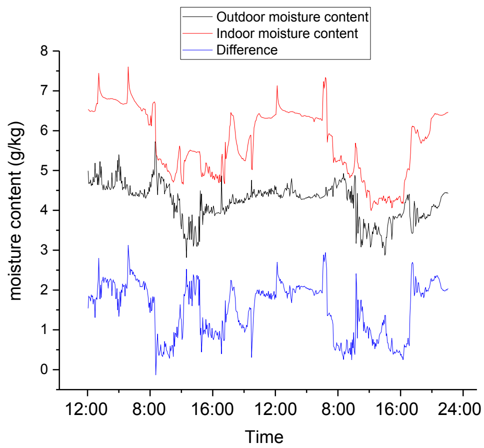


Figure 11(a) Indoor moisture content during Dec. 15-16 of 2016 at Xiangtan

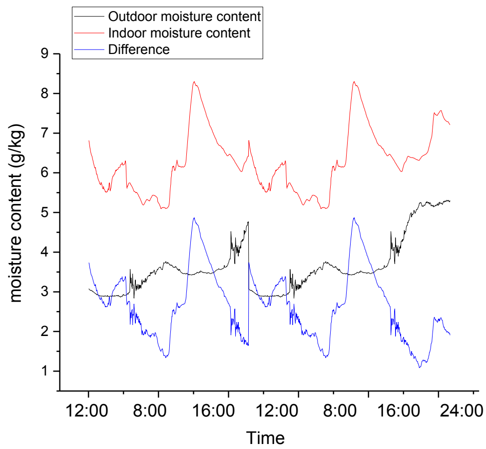


Figure 11(b) Indoor moisture content during Feb. 14-15 of 2017 at Eindhoven

Table 1 Correlated coefficients between indoor and outdoor moisture

	Indoor mean moisture content g/kg	Outdoor mean moisture content g/kg	Difference g/kg	Correlation Coefficient
Xiangtan of China	5.74	4.22	1.52	0.59
Eindhoven of Netherland	6.34	3.79	2.55	0.37

Conclusion

The focus in this study is to employ a preliminary investigation to realize real indoor thermal environmental situation at central China and western Europe. It is found:

1, although Xiangtan's outdoor operative temperature is higher than Eindhoven, its indoor temperature is colder than latter with 5 °C during winter. And the fluctuation of temperature is another obvious issue to comfort of occupants.

2, the Chinese apartment's moisture content difference between indoor and outdoor is much higher than European. In general this comes mainly from bad airtight, but it needs further study to make certain its exact contribution in comparison to other factors, such as porosity of building materials and absorption of vapours, heating operation and occupation patterns etc.

Even though the investigation and analysis given has much limitation because only two apartments from China and Europe have been compared, it reveals the thermal situation in residential buildings at central China. Despite this Chinese family's people had lived there more than 20 years, they still could complain their indoor thermal environment. But when moved to Netherland, they felt much comfortable in the warmer and stable indoor climate.

In terms of thermal comfort, this study has same conclusion as Lin, B., et al. (2016) with uncomfortable of too cold. The difference is that here it has higher indoor temperature. It has similar indoor temperature range as Cao, B., et al. (2016), but here occupants feel too cold. It indicates the occupants feel cold that different from much lower acceptable indoor temperature from Han, J., et al. (2007, 2009). All of these need further study.

A new trend happening in this area is that more and more families prefer to install high-power household heating system by gas or electricity, and then it will consume much more energy than before. But the energy consumption would be probably higher than northern China due to worse thermal insulation and airtight. In a word, improving the performance of existing buildings should be the priority in hot-summer and cold-winter region of China.

Acknowledgement

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Vernacular Buildings

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Design to Thrive

Optimising Residential Courtyard in Terms of Social and Environmental Performance for Ghadames Housing, Libya

Jamal Alabid[1], Ahmad Taki[2]

[1] Architectural Research Group, Leicester School of Architecture, De Montfort University Gateway LE1 9BH – UK jamal.alabid2@dmu.ac.uk
[2] Leicester School of Architecture, De Montfort University, Leicester LE1 9BH UK ahtaki@dmu.ac.uk

Abstract: Vernacular architecture comes from a wealth of knowledge and experience of humans who were able to adjust to the surroundings and adapt to even extreme climate conditions. In fact many old traditional settlements may fail to functionally provide high indoor quality according to the modern building standards. However, these buildings are still seen as a good example of serving the purpose of locals' social life and their ability to effectively respond to outdoor climate. Therefore, this work recognises the need to develop the courtyard concept to meet the social and environmental requirements of today's housing conditions taking the advantage of traditional architecture of Ghadames. The work carried out methods of descriptive and simulation analysis to investigate the environmental performance of existing and proposed residential courtyards employing natural ventilation system in terms of thermal comfort conditions. The optimisation process of the courtyard design not only relied on methods of observation but also householders and professionals' views were considered. Householders and professionals agreed that courtyard houses might be often linked to lower social classes but still serve most of social and climate purposes. The dynamic thermal simulation showed that indoor comfort temperature in a traditional courtyard was found to be at 34˚C. An optimisation design process was conducted to a courtyard building resulted in reducing the indoor comfort temperature to about 28˚C. Further results showed that the new design has improved the daylighting performance at 2.9% of average daylight factor. The work also outlined the applicability of using locally sourced building materials and their capacity to achieve high thermal performance particularly with reference to the use of organic date-palm fibre. It can conclude that the proposed design has integrated the passive climate design strategies to help achieving acceptable indoor comfort conditions and also sustainable features to further enhance locals' social life.

Keywords: Climatic design, EnergyPlus, courtyard house, indoor human comfort.

Introduction

Courtyard housings proved to be one of the best solutions in hot arid settlements and have been developed through experience of trial and error by local builders to serve social and cultural needs (Coch, 1998; Majid et al., 2012). Among a number of research group including Naciri (2012) and Nikpour et al. (2012) the role of the central courtyard in traditional architecture acting as a climate modifier was recognised and considered to be the best residential form in delivering sufficient natural ventilation and daylighting for interiors especially in hot regions. However, it has not been clearly identified in practice how such traditional techniques can be implemented in modern architecture (Bekleyen and Dalk, 2012).

The energy and environmental performance of courtyard buildings has been investigated and well documented in literature including Ben-Hamouche (2008), Al-Masri and Abu-Hijleh (2012) and Mandilawi (2012) who found that a great energy reduction of 54.25% can be achieved compares to conventional building forms. The abandonment of traditional wisdom and knowledge and the partiality of globalisation by many people to imitate western development and selection of inappropriate design and materials led to unsustainable and unaffordable constructions especially in developing countries (Bruen et al.,2014). Therefore, developing new forms of residence that take advantage of local context and new available technology will be the way forward to deal with social and environmental aspects as well as todays' world challenges including energy and nature conservation issues.

Comfort and social needs are the main issues taken into account for optimising the residential courtyard of Ghadames housing and consequently its impact on total energy consumption. The internal centred courtyard is the most common type used in hot arid climate bringing many benefits including reduction in energy and noise, possibility of enhancing the indoor visual environment by opening windows into it and protection from outdoor harshness (Vaisman and Horvat, 2015). As reported in many studies including Abarkan (2000) and Nikpour et al. (2012) the courtyard in residential traditional architecture was an outcome of cultural as well as climatic aspects. However, the courtyard concept was developed and saw radical transformation by the 20th century in Libya as a result of life change and western culture influence (Bilghit 2007).

Research methodology

The research is carried out through methods of observation, interviews and dynamic simulation analysis. A case study of a traditional house was selected to investigate indoor thermal and design conditions of old settlements of Ghadames particularly the social and environmental role of central courtyard. The strategy was to conduct field surveys including temperature measurements during the interviews and simultaneously observe any phenomenal aspects. These aspects may be related to techniques used for ventilation, daylighting or occupants' behaviour supported by drawings, sketches and photos. EnergyPlus is used to first verify field data and test proposed courtyard performance.

The case study climate characteristics

Ghadames lies in the hot arid desert climate characterised with very low precipitation and far less than the potential evapotranspiration with large temperature swings in the daily cycle especially in summer resulting in low humidity rates. The city falls in the most extreme zones within the Libyan climates as located in the Sahara Desert region with almost eight months of hot and dry period and four moderate and partly cold winter period (Zifan, 2016).

Typical traditional house

Old settlements of Ghadames generally were designed to reduce exposure to outdoor conditions and enhance air movement through maximising shadings on buildings and street levels. The majority of traditional houses consist of three storeys and attached wall-to-wall from four sides creating very compact form. Streets and pathways are either fully or semi-shaded covered by first floor extended roofs. The form of the house combines high degree of compactness with minimum exposure to outdoor and relatively small plot area ranges from 25 to 50 m^2. The space organisation of rooms varies according to the privacy level and functionality though. It is therefore constructed in three storeys to accommodate fully-sheltered ground floor consists of usually main entrance with stairs, guest room, storage and cesspit room. The first floor is a semi-private family area centralised by living-room which is surrounded by number of rooms.

The central hall is constructed in double-volume height with steps leading to mezzanine level which also consists of other private bedrooms. Stairs lead up to the roof level where kitchen is found as well as summer shed space used so often at summer nights. In Figure 1 the central living hall represents the inner courtyard of traditional houses which located in the heart of the house built in double ceiling height (4-5m). The 1m^2 roof aperture placed in the central living hall is the main source of daylight and natural ventilation for surrounding rooms. Hence, families spend most of their time in this hall and also practising many social and religious occasions.

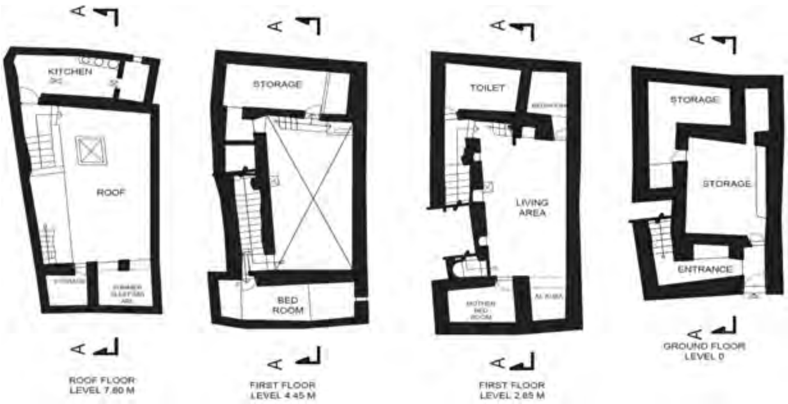

Figure 1. Plans of typical traditional house in the old town of Ghadames

Construction materials

Rocks and mud are the most common building materials in the old town of Ghadames settlements due to the nature of the desert land (Al-Zubaidi, 2002). Rocks are used in foundations and on ground floor for only the first 1.5m height. However, traditional houses constructed not only with sun-dried mud and stone which is mainly used in the bearing walls but also gypsum, limestone and wood are commonly used particularly in roof construction and finishing. Technically, walls are made out of sun-dries mud bricks with approximate digestions of 12×40× (75, 60 and 50) cm as shown in Figure 2.

U-value = 0.321 w/m²k

Thermal resistance = 3.111 m²k/w

Material	Thick-(mm)	Conductivity (w/m-k)	Resistance(m²k/w)
Mud-Brick	500	0.17	2.941
Clay-Mortar	20	0.29	2.33

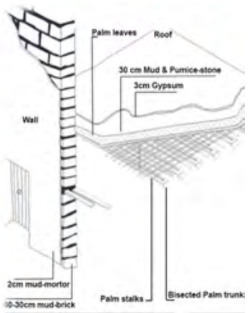

Figure 2. Local construction materials in traditional house

The thickness of the wall varies starting from 75cm on ground level to change at height of 3m to 60cm and then to 50cm at height of 5 to 6m (Al-Zubaidi, 2002; and Allafi, 2012). The size of bricks may slightly vary from building to another as Aalund (1983) stated that brick's size of 40×60mm, 40×50mm and 40×40mm is also found for ground floor, first floor and top floor respectively. The mud bricks are made of a mixture of clay, gypsum and palm date fibre that all mixed up and burred underground for weeks before it is used.

Proposed prototype courtyard house

The proposed design of the courtyard considers various aspects including the climate, social needs and preference, use of land and shared resources, the urban complex and use of renewable energy sources. Figure 3 shows the layout of the ground floor consists of semi-public area for male visitors, semi-private area including the female guest room, kitchen and indoor covered courtyard space as well as semi-shaded carport and garage with a side family entrance. The first floor of the prototype house presents the private family area including inner balcony that overlooking the courtyard as well as summer shed space (loggia) which is used mainly in summer night as part of their tradition and climatic solution. The inner covered courtyard plays an important role in local community life and incorporating this space with elements like balconies, sittings, playground areas and fountain will enhance the quality and performance of entire home.

Figure 3. The proposed design of the courtyard in residential buildings

The courtyard has been moved from the centre as in traditional house to the side position and also from first to the ground floor to integrate certain natural elements includes vegetation and sittings. The courtyard ceiling height has been increased which also offers nice view from first floor balconies and further enhance thermal conditions. Clerestory skylights have been placed in the courtyard roof to enhance daylighting and also promote night ventilation strategy.

Construction materials

Local materials can be efficiently optimised and used in construction as approved to have high thermal performance including the dried-mud bricks, dry limestone sub-soil, and palm tree fibre as an insulation material. DesignBuilder has an editable library which is rich of construction materials and all thermal and physical variables including U-value, thermal and surface resistance, internal heat capacity and reflectance can be calculated. However, there are a number of studies investigated the use of organic materials especially if locally available as an alternative green materials, cheap, sustain longer, reproduced, reused or recycled. With the new technology dried-mud bricks have been developed to enhance its thermal and physical characteristics to achieve great time lag up to 10.5 hours compared to 6.7 hours for the concrete hollow blocks (Kamal, 2011).

In addition, Ghadames Oasis is rich in palm trees and thousands are found around traditional settlements. This type of plant has been under research by many studies testing the viability of its natural organic fibre to be used as an efficient and biodegradable insulation materials (Al-Homoud, 2005; Khiari et al., 2010 and Agoudjil et al., 2011). More recent studies such as Lertwattanaruk and Suntijitto (2015) found that palm oil fibre is a great natural material to be used in industry to replace cement flat sheets to reduce thermal conductivity, optimise heat insulation and decrease its bulk density. Therefore, this study has considered date palm fibre for insulation materials as a green option as Table 1 shows.

Table 1. Wall construction materials in the proposed courtyard

Ext	Material description	Thickness mm	Conductivity W/m deg. C	Density Kg/m^3	Specific heat J(Kg deg. ˚C)
1	Dry limestone blocks	25	1.26	1522	908
2	Sun-dries mud-bricks	150	1.8	1800	712
3	Organic date palm fibres	50	0.08	600	2000
4	Sun-dries mud-bricks	150	1.8	1800	712
5	Gypsum board/mortar	20	0.16	600	1000
In	U-value	**0.211 W/ m^{2}K**			

Courtyard redesign and optimisation

Courtyard configuration

Throughout history the basic plan of a residential courtyard has been developed and modified to meet environmental and cultural aspects (Das, 2006). In this study the design concept and form of the courtyard in traditional housing was investigated and clearly noticed that the form and position of the courtyard plays an important role in modifying the indoor microclimate. Many in literature including (Amer, 2007) and (Heidari, 2010) found that rectangular deep courtyard form performs better for hot or desert climate. In desert climate such as Ghadames the protection of exposed surface of dwelling from intense solar heat and dusty hot winds are key aspects in optimising the courtyard which will have an impact on indoor thermal comfort as recommended by a number of researchers such as (Aldawoud, 2008).

However, there are more than variable have to be taken into account in optimising the environmental performance of inner residential courtyard including orientation, volume, position in relation to interiors. Muhaisen (2006) studied the optimum courtyard proportion (height and ratio) for different climatic zones and found that double ceiling height would determine the best thermal performance in hot arid climate. Hence, the courtyard geometry and proportion and level of exposure to outdoor conditions are considered in this study which will have a significant influence on indoor thermal conditions. However, the study uses a dynamic simulation programme *EnergyPluys* to investigate the performance of existing and optimised courtyard.

Simulation and findings

Traditional house

Simulation is run for typical summer week in July to compare results with actual temperature readings. The average of indoor thermal conditions is slightly higher than the temperature recorded in-situ but remains relatively constant. In Figure 4 comfort temperature (T_{op}) estimated around 34˚C throughout the week inside the living room whilst actual temperature measurements were recorded at 29˚C to 32˚C. This can be interpreted as the microclimate of the old town has been modified by massive green fields and outdoor water surfaces contributed to humidify and drop down ambient air temperature which has not been accounted in the simulation. It is also the technique used to balance thermal indoor conditions during the day and night with aid of less exposure to sun as shown in

Figure 5. The total annual energy use inside the traditional house was found to be 28.87kWh/m^2 as this mainly consumed for lighting and hot domestic water. According to Noguera and Cervera (2012) Passivhaus specified that the annual total energy demand for space requirements should be limited to 20-30kWh/m^2.

Figure 4 Indoor thermal conditions predicted in the central hall of the traditional house

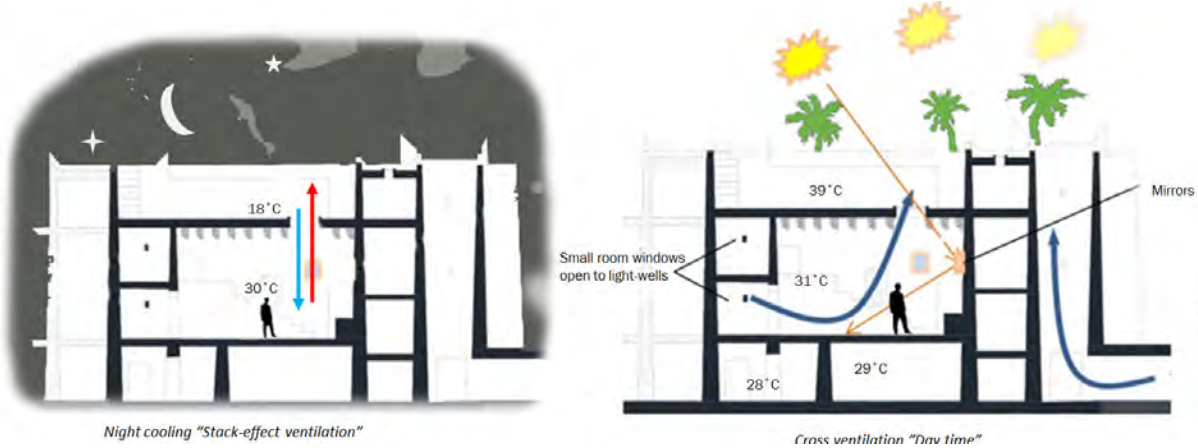

Figure 5 application of natural ventilation inside central courtyard in traditional houses

According to Samaan et al. (2016) EnergyPlus uses one of the best daylighting simulation programmes *Radiance* integrated into CIBSE and LEED calculations. in practice daylight factor of 2% to 5% showed to have a great balance between achieving good daylighting and thermal aspects (CSH, 2010). BREEAM daylight calculations indicate no compliance with minimum standards and the house fail to be adequately lit naturally. However, daylight average inside the central hall has been calculated at 1.21% and indicated poor daylighting distribution.

Table 2. Daylighting inside the central hall in DsesignBuilder

Zone	Block	Floor area (m2)	Min DF (%)	Uniformity ratio (Min / Avg)	Area adequately lit(m2)	Average DF
Living-Room	first floor	17.68	0.07	0.57	5.675	1.21
Total		**17.68**				

Proposed house

A typical summer week in July represents one of the hottest periods in Ghadames where temperatures reach 47˚C during the day and drops down by 26˚C at night. Indoor thermal conditions inside the courtyard were indicated to be far better due to the installation of skylight openings which enhance the night purge ventilation. The temperature was around 28˚C with higher humidity rates than values found in traditional courtyard. In EnergyPlus external openings were set to be open at evening during summer so only that night purge ventilation can take place at the specified time. This showed a significant impact on the heat balance inside the courtyard as can be seen in Figure 6. It indicates that indoor comfort temperature inside the courtyard is relatively constant throughout the typical summer week at 28˚C in natural ventilation mode.

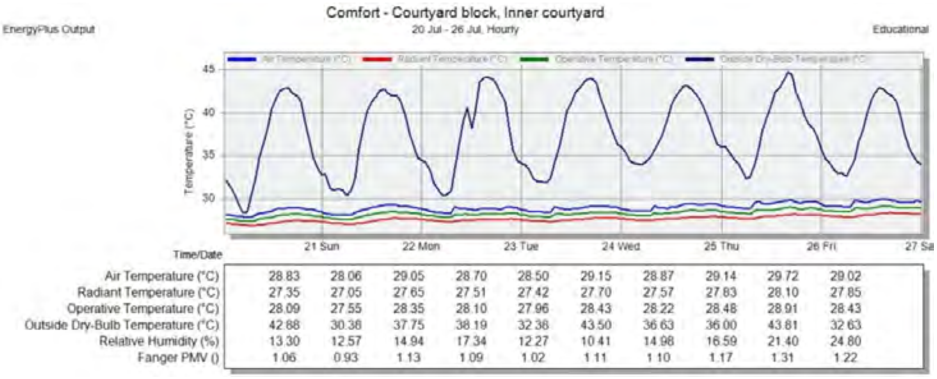

Figure 6. Indoor thermal conditions inside the proposed residential courtyard

However, to achieve the recommended human comfort temperature by ASHRAE 55 which is about 26˚CAC was assumed to be on throughout the summer period from May to October at an average of 8 hours per day. As a result of that a 5.02kWh/m^2 is consumed for space cooling**Error! Reference source not found.**. According to the BREEAM rating the building did not fully achieved daylighting. However, with 15% window-to-wall ratio it is difficult to pass BREEAM credits but fairly can achieve acceptable performance especially in living spaces. In general, the house achieved good thermal performance with relatively good daylighting and the covered courtyard serves as solar room to deliver daylight deeper into interior spaces through skylights as Table 3 shows.

Table 3. Daylighting analysis inside the proposed courtyard

Zone	Block	Floor area (m2)	Min DF (%)	Uniformity ratio (Min / Avg.)	Average DF	Area adequately lit(m2)
Inner balcony	FF	3.960	0.57	0.40	1.4	1.300
Living room	GF	18.880	0.55	0.19	1.2	8.720
Inner courtyard	GF	29.250	0. 70	0.24	2.9	21.320
Total						**31.340**

Conclusion

This study highlighted the significance of both understanding the local architecture and context in designing residential buildings especially in extreme climates such as Sahara Desert. The courtyard in desert architecture has been and still considered to be one of the best options to meet residents' environmental and cultural requirements. Although, traditional architecture is proved to act responsively towards the environment where it stands but may not meet today's living standards. Therefore, this paper aimed to optimise the performance of residential courtyard to enhance the indoor conditions for Ghadames housing. The findings indicated that covered double ceiling height courtyard on the ground floor would have significant impact on enhancing indoor thermal and visual conditions. In addition, it creates a pleasant space for family and integration of natural elements such as water and vegetation would add great impact on indoor conditions. Installing skylights in the courtyard roof have resulted in improving the daylight and night stack ventilation. Local materials readily available found to have high thermal performance and reduce the construction cost which can replace all concrete and some other exported materials.

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Design to Thrive

Vernacular architecture and contemporary production processes, in search of «Relay concepts» between vernacular and contemporary

Linda Bchir[1], Pierre Fernandez[2] and Savitri Jalais[3]

[1] Laboratory of Research in Architecture, National Higher School of Architecture (ENSA), University of Toulouse-Jean Jaurès, Toulouse, France, lynda_bchir@hotmail.com;
[2] Laboratory of Research in Architecture, National Higher School of Architecture (ENSA), University of Toulouse-Jean Jaurès, Toulouse, France, pierre.fernandez@toulouse.archi.fr;
[3] Laboratory of Research in Architecture, National Higher School of Architecture (ENSA), University of Toulouse-Jean Jaurès, Toulouse, France, savitri.jalais @ toulouse.archi.fr;

Abstract: Vernacular approach seems to be a realistic and applicable current response to a search for durability and quality in architectural production. My thesis project aims to explore the concept of vernacular architecture and to highlight the potentials of vernacular concepts so as to include them in contemporary architectural design. Our concern consists studying vernacular in architectural design, while focusing on how we can link the vernacular and contemporary projects today. It thus aims to extract concepts from vernacular architecture, that qualify as part of our research called "Relay concepts" that could serve as project tools today in contemporary design. This work will involve defining the consequences of complementarities between vernacular/contemporary, on results obtained in terms of sustainability and quality in architectural production. What is a vernacular architecture? What are the principle generators, concepts and meanings of the fundamental values of vernacular architecture? What are the lessons that we can extract from vernacular in contemporary architectural design? How can we transfer them? Does the term contemporary vernacular architecture viable?

Keywords: Vernacular architecture, contemporary architectural design, Relay concepts, etymology, repossession

Introduction

To be caught between two worlds: that of a thirst for everything that is contemporary and new in terms of design and at the same time admiring the precious examples that exist in the history of architecture. From this situation, our point of departure was born, in the form of latent questions since my first steps at the school of architecture of Sidi Bou Saïd in Tunis, and was further accentuated during my practice in architecture cabinet. Throughout my academic background, I was awakened by many questions concerning vernacular architecture. The debates that exist around this concept permitted me to discover facts which help to understand what vernacular architecture is in general without being able to define it. This term is often unclear, poorly known, its architecture devalued or called minor, folk, primitive, spontaneous, local, anonymous, self-constructed, an architecture without architects, native marginal, traditional or even rural. This profusion of terms arouses confusion and has led to a various theoretical debate on how best to define vernacular architecture. Later, during my professional internships and my two years of practice in architecture, I realized that in practice these valuable examples of architecture instead of being acquired and used as guides, often, unfortunately, are reduced to formal elements functioning only on the surface, as decoration of buildings or ephemeral acts. Today, I want to give coherence and meaning to my career and find a new way of apprehending, understanding and conceiving architecture by linking the vernacular and the project.

The opportunity to rethink how to apprehend and conceive architecture

Vernacular architecture has long been devalued and underestimated, although 95% of the built environment in today's world, according to the research of architect and urban planner Amos Rappoport (Rapoport, 1972), can be considered as being vernacular. He estimates that only 5% of the buildings in the world are the result of the work of architects. However, it is an architecture that we do not enough speak about, if ever, because it is wrongly considered as a "minor architecture compared to the architecture of architects" (Guindani and Doepper, 1990).

Today, environmental issues and technological advances give another dimension to vernacular architecture and local resources. Many authors speak of a need to define and raise awareness of this architecture that has long been neglected. In this perspective, our theses research aims at highlighting the lessons we can learn from vernacular language in contemporary architectural design, while focusing our reflection on how we can link the vernacular and the project today. It aims to extract concepts from vernacular architecture, that qualify as part of our research called "Relay concepts", that could serve as project tools today in contemporary design. What is vernacular architecture? What are the generators principles, concepts and meanings of the fundamental values of vernacular architecture? What are the lessons that can be extracted from vernacular in contemporary architectural design? What concepts of vernacular architecture do contemporary architects reinterpret and reintroduce into their projects? How can they be transposed? Are vernacular and contemporary antinomic? Does the term contemporary vernacular architecture viable?

These are the fundamental questions which this thesis attempts to answer.

Knowledge transfer strategies, from local to global, from the most specific to the most general

Vernacular architecture is strongly influenced by the local context, cultural patterns and the impact of physical environments; it refers to the specificities of a population and a territory. Enforcement remains variable from one country to another, and its design is in permanent evolution, adaptable to the constraints of specific regions. Thus, even though vernacular architecture is a local architecture, could it have universal validity criteria (constants)?
This last seem to be in the form of proven architectural concepts of vernacular architecture, generalizable, adaptable and transposable to other contemporary situations. We thus formulate the hypothesis that the approach of identifying universal validity criteria (constants) in vernacular architecture, could help us develop a research approach for contemporary architecture based on the proven concepts of vernacular architecture, as well as to constitute a corpus of knowledge and contribute to a reconciliation between the vernacular and contemporary. The vernacular approach seems to be a realistic and applicable response to a search for durability and quality in architectural production. We thus arrive at the hypothesis that vernacular architecture will only be a source of contemporary inspiration, inasmuch as the architect is able to grasp the deeper meaning of vernacular architecture. This may also have an impact on the pedagogical approaches of

higher education, which must be accompanied by an emphasis on the lessons we can learn from the vernacular in contemporary architectural design.

Method relating theory and practice

The methodology we propose is based on the combination of two approaches; it will be built step by step by relying on different corpuses:

Theoretical corpus of epistemological and lexical order

My theoretical approach proposes to explore the notion of the vernacular through its etymology, thus understanding how the vernacular word was introduced into the history of architecture and history of the French language.

A comparative study of the use of words close to vernacular, such as: popular, common, ordinary, traditional, native, spontaneous, in the theoretical and critical texts of architecture is essential to see whether these words refer to same objects. The objective would be to be able to locate the vernacular in relation to these terms that are close to it. "All these words as alone and together can reveal an architectural image, the nuances that lie between them require us to make an investigation to better approximate the vernacular concept" (Mercer, 1979). We therefore wish to take advantage of this study to clarify our vision of vernacular which is quite vague and position ourselves in the great theoretical debate about its definition.

Our bibliographic research will be deepened within the framework of the thesis and will focus on the most important critical and theoretical studies of vernacular architecture such as:

- The work of Frédéric Aubry (Aubry, 1999) at the Federal Institute of Technology in Lausanne, who was able to create with his students a "collection" of more than 680 models 1/20 scale that takes up vernacular works. These mockups have a pedagogical purpose and serve as predefined templates to assist students during their process of transposing and adapting old techniques to contemporary situations.

- The research of Pierre Frey (Frey, 2010), which represents a starting point in our reflection. They give back a new dimension to vernacular architecture. These lead to an exhibition of the work of Frédéric Aubry (Aubry, 1999) and then to the publication of the book "Learning from vernacular" which questions the meaning and relevance of a vernacular architecture today.

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- Welsh School of Architecture: The open-air museum at St Fagan serves as a laboratory for first year students who have the opportunity to observe and analyze the collection of Welsh reconstructed buildings on site for a week. A new approach to teaching is proposed in this school of Welsh architecture, the latter is based on the use of vernacular architecture as a model for the environmental design of buildings.

- The Atlas of vernacular architecture of the world (Vellinga et al, 2007) which brings together an impressive stock of vernacular works studied, listed and classified according to specific criteria. This encyclopedia is the first to show the remarkable diversity of buildings built and inhabited by people of more than a thousand cultures.

On the other hand, our research will also cover Internet sites of organizations dedicated to the study and enhancement of vernacular architecture such as ICOMOS (International Council of Monuments and Sites), CIAV (International Scientific Committee On the vernacular architecture), CERAV (National Center for Textual and Lexical Resources).

A pragmatic corpus based on analysis of concrete projects

My field work will be done with a rigorous and referential methodology and will follow the following approach and logic:

- An architectonic observation followed by analysis to recognize constant adaptations, of a vernacular architecture.
- These adaptations will be analyzed as a response to the socio-cultural and environmental environments, in order to understand the path of a vernacular architecture that depends closely on the site, the landscape, the climate and the materials.
- To identify and analyze architectural concepts from the vernacular world, to sort them from the most local to the most global, from the most specific to the most general, then to combine them, to synthesize them, and finally to find constants that are conceptual and transposable to others situations.
- Identify and analyze contemporary architectural projects bearing these previously studied, synthesized concepts, coming from the vernacular world and implemented in contemporary architecture (In order to explore the process through which, some contemporary architects have looked at the vernacular architecture).
- Understand how, according to what logic and how they were transposed?
- Define the consequences of complementarily between vernacular/contemporary, on the results obtained in terms of sustainability and quality in architectural production.

All this investigation will be done using the techniques of pedagogical investigations namely:

- Site visit which allows a direct visual perception of the built environment.
- Methods of surveying to update the material support of this research (topographic maps and plans at different scales and at different times).
- Comparative study: My case studies with countries forerunners of the contemporary reinterpretation of ancestral constructive tradition.
- Reading, sorting, analyzing, interpreting and synthesizing of various data collected.

Towards an intercultural ground, case study of vernacular and contemporary projects in the South west of France and in the south of Tunisia

I would like to point out that I will enjoy my Tunisian-French cultural background in the selection of Pragmatic Case Studies. It would be more judicious to choose examples; rich in teachings, from diverse origins (located in different parts of the continent, with a rather different historical and cultural development), bearing one or more vernacular concepts preferably, easily illustrated with a picture or drawing. In our choice of case studies we tend to favor those from the UNESCO World Heritage database, and those that are recognized as representative of the vernacular architecture.

South west of France: The vernacular architecture of the Landes of Gascony

The territory of our study is 'the Landes of Gascony' (Figure 1), limited to the north with the Bordeaux vineyards, south of Chalosse, in the east by the Garonne and to the west by the Atlantic Coast, Situated in the Aquitaine region (South West of France), geographically located in the Midi Atlantic.

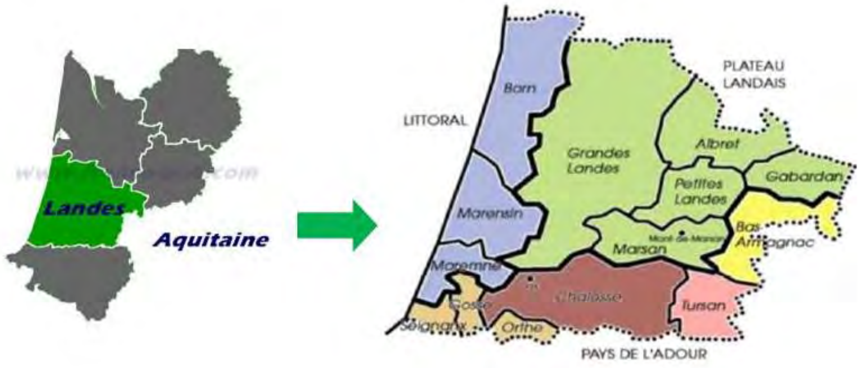

Figure 1. Territory of our study: the Landes of Gascony.

The Landes vernacular house (Figure 2):

Is a very illustrative example of vernacular architecture, rich in studies, for all that theoretically we can read on vernacular and bioclimatic architecture, we see it and we live through its vernacular built environment. After my beginnings of research, my site visits and my architectural observation I think that the Landes constitutes a wealth of didactic because of its buildings built, which is a traditional urban ensemble that retains the marks of an ancestral know-how in construction and architecture.

Figure 2. The Landes vernacular house.

Traditional habitat of landes has demonstrated its quality in terms of constituents of landscape, respect for the environment, adaptation to climate, use of local resources and know-how. According to "CAUE" of Landes : «The Landes house is an example of the persistence of an architectural type that denotes the adaptation of its visible characteristics to its geo-climatic environment» […] «An architectural and patrimonial identity in the Landes, very nuanced and stratified in time, which invites us to rethink contemporary modes of production".

For these reasons this type of vernacular architecture will bring to our study the basic elements which will also allow the analysis of other examples of vernacular architecture throughout the world.

In figure 3, we illustrate an example of project which deploys a contemporary architecture that draws references to the vernacular Landes context.

Figure 3. Cocon landais - WHY Architecture: An architectural firm that intervenes in subdivisions by reinterpreting the vernacular architecture of the Landes houses.

South of Tunisia: The island of Djerba

Djerba (Figure 4) is an island of 514 km^2 (25 kilometers by 20 and 150 kilometers of coast) located in the southeast of Tunisia. It is the largest coastal island in North Africa. The Tunisian government has proposed Djerba for a future classification on the UNESCO World Heritage list.

Figure 4. Territory of our study: the island of Djerba

Vernacular architecture of Djerba:

It is a very illustrative example of vernacular architecture, rich in studies (Figure 5). By contemplating the vernacular buildings in Djerba, we felt that they are in symbiosis with the environment and that their mass melts in nature; there is a perfect harmony between the building and the natural environment. This is due to the small scale of the buildings; there is neither ornamentation nor openings (due to the discretion of Djerbian (culture and religion) on one side and its small size on the other hand), their color (The omnipresence of white) and the materials used that come precisely from nature.

Figure 5. Model which illustrate the vernacular house of Djerba, derived from the work of Frédéric Aubry (Aubry, 1999) at the university or federal institute of technology in Lausanne (Learning from vernacular).

Many contemporary architects (Figure 6) have been strongly influenced by the vernacular architecture of Djerba and interpreted in a contemporary way to reach a compromise between vernacular and contemporary.

Figure 6. Ba-studio: Samia ben-Abdallah architect, elected as ambassador of the ecological architecture in Tunisia.

EXPECTED RESULTS: From strategy to implementation

The ultimate goal at the theoretical level, will be to present a complete investigation of vernacular architecture in order to contribute to the progression of its definition and to try to clarify the confusion that prevails, To achieve this, we thought of the idea of elaborating a landmark consisting of two axes: a historical axis (from oldest to newest) and another spatial one (from local to generic). The objective would be to be able to classify these various lexical elements close to the vernacular and to position them according to this landmark. It will be a working and discussion tool which, in our opinion, should enable us to situate the vernacular in relation to these terms which are close to it.

The ultimate goal on the pragmatic level, therefore, will be to build a corpus of knowledge, which will take the form of a repertoire of «Relay concepts» between vernacular architecture and contemporary architecture. It is a matter of bringing these architectural concepts together in a data bank enriched with new knowledge in the field. It would offer a typology of architectural concepts previously studied, synthesized and allowing a fast and efficient reading for eventual appropriation. On the other hand, there is already an initiative led by Pierre Fernandez (my thesis supervisor) in the direction of my research work under the name of "Thinking the relationship between architectural quality and environmental quality" 'materialized by creating a directory relay concepts of architecture and environment.

We wish to clarify that this is certainly not developing pre-established recipes. But rather to propose a methodological approach that can serve as references for integrating vernacular concepts in contemporary architectural design.

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Design to Thrive

Revitalizing traditional knowledge: The sustainability of the vernacular house in the northeast of Mendoza (Argentina)

Matías Esteves[1]

[1] Instituto de Ciencias Humanas, Sociales y Ambientales, Consejo Nacional de Investigaciones Científicas y Técnicas, Mendoza, Argentina, mesteves@mendoza-conicet.gob.ar

Abstract: This research explains the relationship between sustainability, traditional knowledge and thermal comfort in vernacular housing in the non-irrigated drylands of northeastern in the province of Mendoza, Argentina. The analysis of rural vernacular housing is presented as an opportunity context to deepen in the traditional knowledge of the inhabitants regarding the bioclimatic strategies that unfold in order to reach comfort in territories characterized by limited availability of natural resources, with extreme climatic conditions and no infrastructure. The objective is the description and characterization of the bioclimatic strategies currently developed focused on the materialization and the operation of the house. According to the fieldwork and the interviews carried out it is observed the use of natural materials predominates, although industrialized materials are incorporated. Also, the use of the shadow is a key in the strategies to reach comfort. The results show that the strategies adopted by the inhabitants are the best way to acquire comfort with the resources they have available. This derives from empiricism and from the traditional knowledge they have inherited about materials, constructive forms and knowledge of the climate. For this reason, rural vernacular housing remains as a sustainable architecture.

Keywords: Vernacular house, traditional knowledge, bioclimatic strategies, sustainability

Introduction

More than half of the energy consumed on the planet is linked to the construction, both in materials production and construction, as well as in the maintenance and the operation of buildings. For this reason, the construction of the habitat represents one of the most significant physical impacts on the natural ecosystem (Sanchez, 2005). Faced with this situation vernacular architecture is a target again, due to the fact that in the international literature, several authors agree on pointing it as a model of sustainable architecture, although it is mainly linked to a pre-industrial era. Anyhow it remains in force, even though it presents adaptations to adjust its operation to the new territorial challenges (Esteves, 2016).

Vernacular architecture is deployed as a social and cultural complex system. It is originated from the culture-nature duality and it directly reflects the ways of living (Tilleria, 2010) in tune with the physical space where it is located (Coch, 1998). The International Council on Monuments and Sites (ICOMOS), in its Charter on the Built Vernacular Heritage, defines this architecture as *"the fundamental expression of the culture of a community, of its relationship with its territory and, at the same time, the expression of the world's cultural diversity"* (ICOMOS, 1999:1). In this Charter its characteristics are summarized as follows: 1.

A manner of building shared by the community; 2. A recognizable local or regional character responsive to the environment; 3. Coherence of style, form and appearance, or the use of traditionally established building types; 4. Traditional expertise in design and construction which is transmitted informally; 5. An effective response to functional, social and environmental constraints; 6. The effective application of traditional construction systems and crafts (ICOMOS, 1999:1)

All these characteristics link it directly with sustainability as it recognizes the local climate, the materials used, the users and the traditional knowledge transmitted informally among generations. The traditional knowledge involves the accumulation of knowledge, techniques and tools within a community (UNCCD, 2005) that shows from the empiric a certain understanding about the characteristics of the natural ecosystem. Although in several texts the traditional techniques and knowledge are associated with a cultural backwardness, many organizations and authors (UNCCD, 2005; Rabey, 2004; Esteves, 2016) have emphasized and demonstrated the importance that they present for sustainable development since they involve an approach at local level where the inner characteristics of a specific territory are rescued.

Characterization of the area of study

Topography

The area of study is a broad arid plain that is structured by dunes up to 20m height, alternating with indents and sinkholes. This area has been affected by strong processes of desertification since the middle of the 20^{th} century. This has involved the lack of surface water and the disappearance of forest areas (Roig et al, 1991).

Climate

Desert-semi-desert type, where the recorded temperatures present an absolute maximum of 42ºC in summer and an absolute minimum up to -10ºC in winter, with large daily and annual thermal amplitudes. The rainfall regime is mainly characterized by the presence of summer convective storms, although annually are recorded between 50mm and 150mm of rain, depending on the area. This added to the lack of surface water sources, the relative humidity ranges between 48% and 68% (Estrella et al, 1979).

Population and productive activities

The productive activities are small-scale and family-type. They are mainly based on the goat rearing and in the manufacture of handicrafts. In some cases, the products that are obtained are destined to the extra-local market and in another cases they retract on the family for self-consumption (Torres, 2010). The population is composed of several families that are located in the territory in two ways: in small settlements located on the banks of the Mendoza River in populations that do not exceed 40 houses, or located in dispersed houses into the interior of the territory around old lacustrine complexes, dry nowadays. The present work focuses on the study of these dispersed houses.

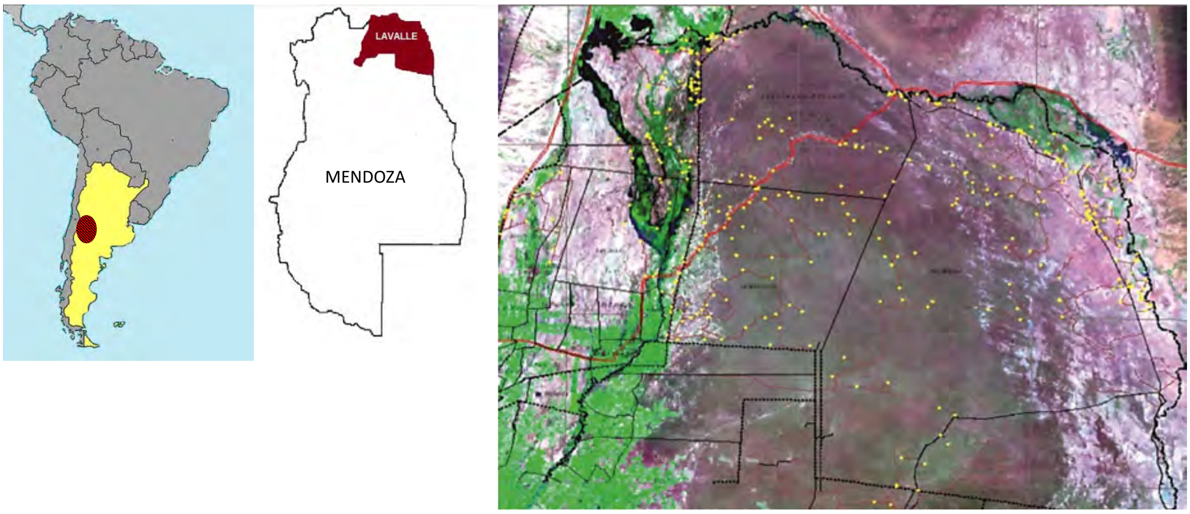

FIGURE 1. Geographical location of the area of study. Each yellow dot indicates the location of a dispersed dwelling. The dispersion of them is linked to the arid characteristics of the territory. Source: SIG DESERT - LaDyOT / IADIZA.

Methodology

Fifteen dwellings that are characterized by their isolation and dispersion in the territory and their direct dependence on nature were analyzed. They lack of basic infrastructure and services to obtain artificial comfort conditions.

With the purpose of characterizing the bioclimatic strategies used to reach comfort and to investigate the existing traditional knowledge related to habitat construction, qualitative methods have been used, such as participant observation and in-depth interviews.

Description of the houses

These dwellings are characterized by two juxtaposed spaces: the interior space and the intermediate space.

The interior space is configured as a sequence of adjoining rooms without corridors or spaces destined exclusively to the circulation (Pastor, 2005). This are the rooms used at night for sleeping and, to a lesser extent, for cooking and dining. The use of mud earth stands out in these rooms: Adobe walls -varying thickness from 0.25m to 0.30m- or quincha –mud and cane mixture with a thickness of 0.10m to 0.15m-) and in few sectors, it is noticed the use of bricks (thickness 0.20m). In all cases, the joints between masonry are made with mud mortar. In all homes, the ceiling is flat roof with minimal grade and its structure is materialized with poplar logs. Over this, it is placed a cane grate and finally a blend of mud. On the outside it is common to find an expanded polyethylene sheet to reduce the action of rain on the mud roof.

The intermediate space is attached to the interior space (figure 2), mainly on its north side. In this space most of the daily activities are performed during the day, both in winter and in summer. It is materialized by wooden pillars made with algarrobo (*Prosopis flexuosa*) and beams of the same material, although it is usually combined with poplar logs. The roof is materialized with cane making a distribution mesh, a sheet of polypropylene and on this, a blend of mud. To a lesser extent, light roofs are resolved with industrial materials such as synthetic mesh or corrugated zinc sheet.

FIGURE 2. Photographs of dwellings: Volumes and materials used and the natural context of the site. The interior and intermediate spaces are appreciated (Source: Author)

Self-construction is frequent for the building and extension of the house as well as for the maintenance of housing, where the whole family participates with the help of neighbors or relatives. This situation inevitably involves traditional knowledge and the knowledge transfer among generations.

Regarding how they obtain the materials used in the construction of the house, all the interviewees agreed to indicate that they use the resources available in the natural environment because of their low cost; even in the case of adobes or quincha they are manufactured by them. Interviews data indicate that the inhabitants show certain knowledge of the advantages, disadvantages and characteristics of each material, in terms of construction techniques, quality, time and frequency of maintenance and thermal behaviour. In the same interviews it is also shown that they prefer the use of natural materials for two main reasons identified in the fieldwork: On the one hand, because of the continuous use in time of this materials and the knowledge transfer from generation to generation results in the identification of the social group. On the other hand, for the trial and error process the inhabitants have verified the thermal efficiency of these materials to the external climate, even comparing them to industrial materials.

The most used materials are those made with mud such as adobe walls -width ranging from 0.25m to 0.30m- with a density of 1600kg/m^3 and thermal conductance of 0.70W/m^2°C and the quincha wall (Cuitiño et al, 2014) considering a width of 0.10m, density of 1450kg/m^3 and thermal conductance of 1.34 W/m^2°C. The canes used in the ceilings have a thermal conductance equivalent to an expanded polystyrene sheet of 7mm thick (Cuitiño et al, 2005). The blend of mud used in the covers (0.10m of mud plus a row of cane) has a density of 1450 kg/m^3 and thermal conductance of 1.34W/m^2°C. Because of these characteristics, they are more insulating than industrialized materials, where the brick wall (thickness of 0.20m) has a density of 1800kg/m^3 and a thermal conductance of 2.12W/m^2°C, while the corrugated zinc sheet has a density of 2700 kg/m^3 and thermal conductance of 4.47 W/m^2°C). It also affects the morphology of housing, as its compact form, helps to obtain greater thermal inertia against the variations of the external climate.

In order to inquire the bioclimatic strategies developed by the inhabitants to achieve comfort, it was used in the first moment the diagram of Givoni adjusted by Milne et al (2009) with the aim of analyzing the strategies that should be considered in the area, to later corroborate in the fieldwork its use. It has been chosen to place in the graph of Figure 4 the critical months (January and July) and an intermediate month (April). According to the diagram, in winter the strategies to reach comfort would be solved mainly with passive solar heating and only a few days and cold nights auxiliary heating, besides the use of thermal mass, already exposed in the previous paragraph. In summer it is indicated the use of natural or artificial ventilation, thermal mass and night cooling.

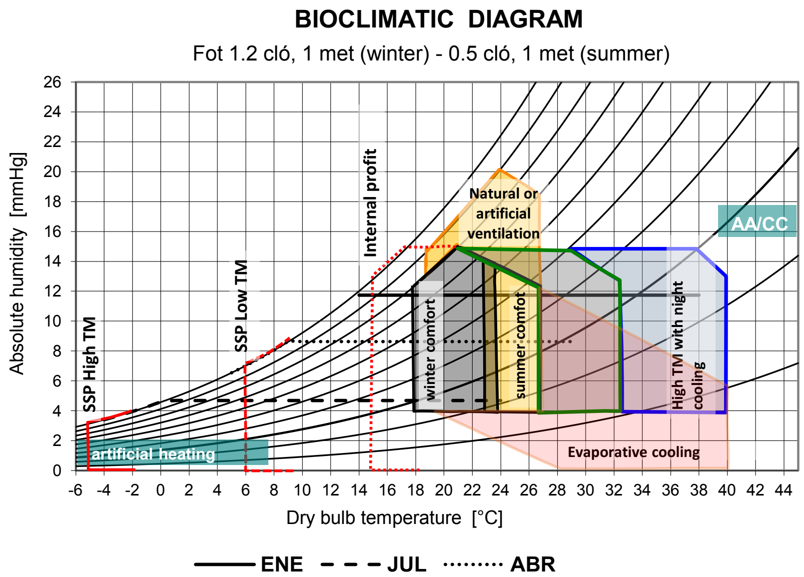

FIGURE 3. Givoni diagram with bioclimatic strategies to achieve comfort according to temperature, humidity and air characteristics.

In tune with the diagram, in the fieldwork they are noted the strategies the inhabitants deploy to achieve thermal comfort. During the summer season, the inhabitants sprinkle water in the intermediate spaces and in the interiors in order to generate evaporative cooling and ventilation to reach a microclimate. This practice is already commented by the artist Roig Matons in his trips to the site since 1930, as a local practice to reduce temperatures (Roig et al, 1999), which indicates the knowledge inherited from past generations.

It is also noteworthy that there prevail small windows, which purpose is to avoid the direct incidence of solar radiation and to prevent the exchange of temperatures between the indoors and exterior. Also, windows are found in all the orientations for the use of cross ventilation for night cooling; this aspect is reinforced in the morphology of the house because they are adjoining rooms without corridors or spaces destined exclusively to the circulation.

The use of the intermediate space is also an important element as this space acts as a mediator, as a nexus between the interior space and the external climate. In the intermediate space most of the daily activities are carried out, taking advantage of the sun setting in winter but blocking the radiation in summer, generating a shadow space (Figure 4).

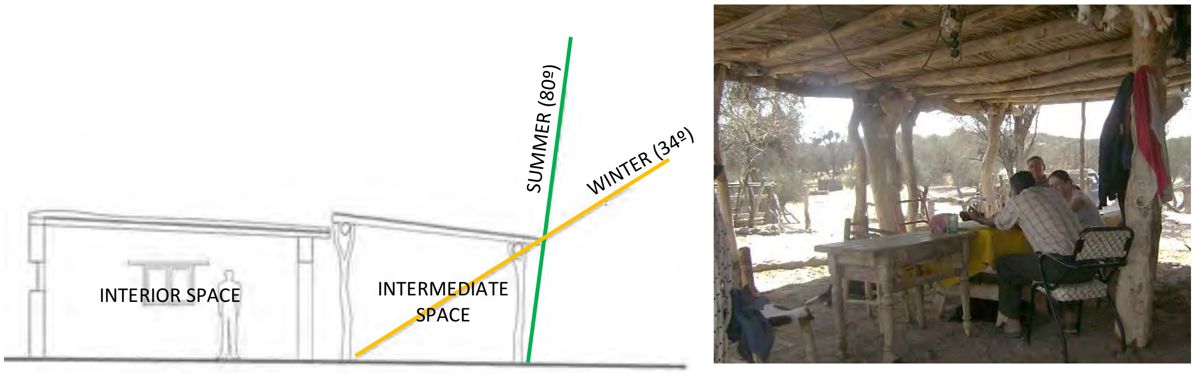

FIGURE 4. Sunlight. Schematic section showing the angle of solar incidence in winter (June) and summer (December) at midday and a photograph of the intermediate space (Source: LaDyOT, IADIZA).

According to the analysis of the comfort temperature throughout the year, the shade is a key strategy to contribute to the comfort. Figure 5 shows the necessity and type of shade (temporary or permanent) according to the solar trajectories of the place and these are based on the time of year and time of day.

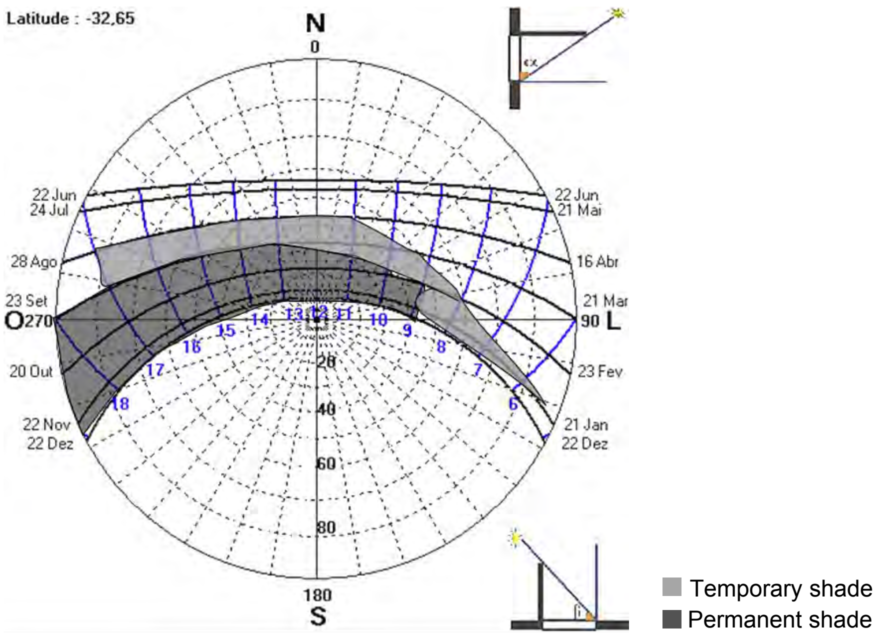

FIGURE 5. Type and necessity for shade during the year.

To obtain temporary shade, exterior elements are used in windows made of cane, wood and synthetic mesh (Figure 6). In respect of permanent shade, it is registered the use of horizontal eaves and the intermediate space that is located mainly towards the north. These elements are made of natural and industrialized materials, which vary according to the ease of assembly, orientation of the window, costs and availability of natural materials on site.

FIGURE 6. Elements used to protect the windows and intermediate spaces made with different materials.

It is clear that the strategies adopted by the inhabitants result in the best way of acquiring comfort with the resources - social, economic and ecological - that they have. In addition, the intangible aspects involve the traditional knowledge produced by experience through trial and error process to achieve the best way to link with the natural ecosystem. For this reason, the sustainability of the vernacular housing in the northeast of Mendoza not only implies the approach of materials and constructive techniques, but also the practices and knowledge that influence its functioning.

Conclusion

In the vernacular housing of northeastern Mendoza in the Center-West of Argentina, various passive strategies are used to achieve comfort that are directly linked to the traditional knowledge inherited from generations that involve accurate knowledge regarding the climate.

The adoption of industrialized materials in the materialization of housing shows the capacity of resilience of the population, although they prefer the use of natural materials, as they recognize the advantages they have regarding thermal insulation. It is observed that the changes are in terms of materials and not of knowledge to achieve comfort. In this sense, the knowledge regarding the need for shade, ventilation and thermal mass has not disappeared and remains in force. For this reason, it coincides with UNESCO when it argues that traditional knowledge is constantly recreated in the adoption of new materials or in the replacement of materials that are no longer available in the environment (UNESCO, 2003). This helps to keep sustainability "alive" since its permanent readjustment.

It has been tried to show both the traditional knowledge and the bioclimatic strategies as allies of the local sustainability and that they derive of the accurate knowledge of the inhabitants regarding to the characteristics of the natural ecosystem. The vernacular architecture that sometimes can be classified as simple encloses precisely in its simplicity a deep knowledge of the natural and cultural environment where it is located and therefore implies the revision of sustainable strategies or forms that it deploys to revaluate it in the current production of architecture.

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Building environment assessment methods and social studies of rural villages in Yunnan and urban development in Chongqing City, Southwest China

Yun Gao[1], Adrian Pitts[1], Lili Dong[2], Guo Chen[1]

[1] Department of Architecture and 3D Design, University of Huddersfield, Huddersfield, UK, email for correspondence: y.gao@hud.ac.uk
[2] Faculty of Architecture and Planning, Chongqing Jiaotong University, Chongqing, China, email for correspondence: 12798062@qq.com

Abstract: Recent urbanization processes and corresponding government policies in China have highlighted the need for much greater understanding of sustainable development and the requirements for sustainability in settings that are very different in rural and urban regions. This paper examines practice and knowledge linked to typical vernacular houses constructed since 1950 in Yunnan Province and regional buildings in Chongqing City in Southwest China. Both areas have played crucial roles in contributing to regional architectural design since the beginning of the 20th Century because of the diversity arising from numerous ethnic groups and various climate types and topography features in the region. The study explores how academic and end-user knowledge accumulated and developed, and how this has revealed social, cultural and political influences on how designers and consumers were motivated towards sustainable design over the same time period. It is argued that locally shared knowledge bases should be considered important for informing governmental policies, planning strategy and consumers' preferences, as well as influencing actions and social acceptance in relation to sustainable development. Furthermore, sustainable design should not be regarded as a contemporary new idea, but one that has its roots in the historical changes in built environment design and practice.

Keywords: Rural and urban development, regional architecture, local knowledge, sustainable development

Introduction

The concept of sustainable building design has been widely used in different countries and regions, and much research has been done to examine the suitability of international and national sustainable building assessment criteria for use in particular regions and societies. McCool and Stankey (2004) stress that the concept of sustainability is socially and culturally related, however, many studies point out that local cultural and social dimensions of sustainability have often been excluded in the assessment (Brand and Karvonen, 2007; Hueting & Reijnders, 2004; Liao, He, 2015). Zhang (2015) finds that the existing studies mainly focus on the environmental aspect of green building while other dimensions of sustainability, especially social sustainability, is largely overlooked. Zhao et al. (2015) analyzes the social problems of green buildings from the humanistic needs to social acceptance and argues that social processes with consumer engagement and participation needs to be considered in design, construction and operation processes to improve users' happiness and productivity. However the consumers are not always readily motivated or may even prefer expensive technological "gadgets" for reducing energy use. To really reflect preference and influenced actions, social acceptance should be analyzed to fully gauge interest and perspective of the people.

This investigation seeks to determine various attempts being made to engage in sustainable design and construction ys in Southwest China. It is argued that the knowledge accumulated and developed over historical periods have revealed social, cultural and political information on how designers and consumers were motivated for sustainable design in the past. Scoones suggests that the importance of knowledge bases of sustainable design and construction need to be considered as asset distinctive from the other five aspects of 'capital': physical, financial, human, social and natural. Shared local knowledge capital can dynamically and continually evolve within communities and support the livelihood and wellbeing of people (Scoones 1998). This study investigates locally shared knowledge that developed in both rural areas and urban cities in China. Although reflected in different ways, they have had significant impacts on decisions for building regulations and planning strategies, and have informed user and consumer preferences for sustainable ways of life. There has been a continuity of thought and action in architecture of what is termed "sustainable design" today, both in rural and in urban development in China since the 1950s.In particular, this paper examines changes that have occurred since the 1950s in practice and knowledge linked to typical vernacular houses in Yunnan Province and in regional buildings in Chongqing City, Southwest China.

The analysis of regional buildings commenced with anthropological studies of ethnic group houses in Yunnan and cultural studies related to indigenous buildings in Chongqing which have occurred since the beginning of the 20th Century. The regional architectural 'knowledge' had developed and been re-interpreted from architectural theories derived from Russia in the 1950s and 1960s and which were then influenced by theories from the West from the 1980s, including the latest concept and theories of "sustainable architecture". The project entails both analytical and interpretive methods of textual research and is also based on materials collected in field studies in Yunnan province and Chongqing city.

The study seeks to explore how the rich and diverse construction traditions in Yunnan and Chongqing reveal their historical roots that are radically different from how the concepts of sustainability and environmental design developed elsewhere. In particular it considers how the concept of the sustainable built environment, particular in its cultural and political dimensions, has been associated with the heritage of vernacular buildings in rural and regional buildings in urban areas. It also considers how local shared knowledge and knowledge from academic study have been considered as an asset directing local government policies and planning strategies. On the other hand, these studies also suggest that new market developments have brought new knowledge to professionals and users. Incentive policies and mandatory regulations are needed to achieve overall sustainable development in the context of China's combined central planning and modernised market economy. To apply the different theories and sustainable assessment methods successfully in the local context, this paper argues that the appropriate sustainable methods and assessment indicators to be used, should take account of local knowledge bases that have accumulated in the past.

Rural development in Yunnan

Yunnan is a diverse part of China with representation in the population of 25 out of the 55 officially recognised ethnic groups in China. Villagers' traditional knowledge of designing and building their own houses in the context of special natural environments formed local shared knowledge capital. The earliest systematic studies of vernacular houses of villages and rural settlements inhabited by these groups were carried out in the 1950s and 1960s. From 1950 to 1963, in order to understand and carry out the classification of the ethnic groups in Yunnan, two stages of identification and investigation of ethnic villages were carried out. More than 1,700 anthropologists, ethnologists, sociologists, architects and artists visited villages to investigate and provide 'scientific' reports about the ethnic group life (Ma, 1999). This was the first time that rural settlements were studied with scientific objectivity; a process that had not been evidenced in previous examinations. The survey focused on the use of traditional materials, construction techniques and characteristics of different houses of ethnic groups, as well as how the vernacular houses had evolved to suit the natural environment, the economic conditions and ethnic group habits. The ‘aesthetic’ aspects of vernacular houses and habitat settlements, represented by a large number of artistic works, were also introduced to the general public in the country. This partly contributed to creation of Yunnan as a thriving tourist attraction after the 1990s.

Following field studies carried out by researchers in the 1950s, four classifications of houses with different materials and technologies were identified in Yunnan. These were initially considered as representations for different stages of housing development over an extended period of history; in chronological order: Ganlan houses (stilt houses raised from ground), Tuzhang houses with adobe or earthen walls, Jinggan houses with overlapping logs serving both as walls and load bearing structure, and Courtyard houses(Figures 1 and 2).

Figure 1. Stilt house and courtyard house. Photos by Yun Gao

Figure 2. Tuzhang and Jinggan houses. Photos by Yun Gao and Adrian Pitts.

The study of vernacular houses in the place where they were found was called “studying in a live museum” with examples showing “primitive” houses and more developed ones co-existing at the same time. The purpose of surveying ethnic groups’ houses was to understand better the cultural heritage of vernacular houses and their use in contemporary design in order to inherit and develop the tradition in contemporary architectural design (EGYVH, 1986). The studies also defined the classification of ethnic groups and their villages and houses by their links with the ethnic group history, religions, and habits. This academic knowledge about ethnic groups and their built environment directed the planning strategies afterwards.

Following the economic growth in the 1980s, unlike villages in coastal areas that developed small industries, the majority of villages in Yunnan had their primary income from agriculture. China's fiscal systems were a combination of subsidies and taxes. Financial support from the local government and the planning of tourist villages were crucial issues to support development. Local policies and plans inherited the classification methods developed from anthropological studies in the 1950s and 1960s, but with a shift of understanding. Rather than emphasising different forms of houses as representatives of different historical stages, new planning considers all traditional forms of houses having equal cultural values that needed to be protected (Gao, Pitts, Gao, 2014). Surveys of villages for planning strategies after the 1990s used four survey categories for reference as follows:

Table 1: Categories of Village Houses

Categories	Criteria	Policy guidance
First category	Well-preserved traditional houses that have embodied historical and cultural values	Protect
Second category	Traditional houses that are in a derelict state and require renovation	Protect, renovate
Third category	Those using a mixture of traditional and contemporary styles; many of which may have employed contemporary technology and materials but try to imitate the traditional styles at the same time	Recommend to modify
Fourth category	Houses that have used contemporary/modern materials and technologies and had no consideration for traditional forms	Recommend to rebuild

Villages generally have more houses in the third and fourth categories than the first two, because they were influenced by widespread development of urbanization processes, and there was a disproportionate rate of replacement of vernacular style houses by new concrete and brick houses. The majority of villagers adapted to market liberalisation and improved transportation infrastructure by giving up the wooden houses and built with new materials such as bricks and concrete. The traditional knowledge of timber houses was considered less useful, however, farmers in the studied villages still help each other to build and increasingly improve their knowledge of new materials and technologies. The cooperation in housing construction maintained the value of culture and a villager's sense of belonging over long term development. At the same time, due to the amateur nature of the local construction teams, new houses have common problems of insufficient anti-seismic or thermal performance (Pitts, 2016). Action plans therefore needed to balance between those involving self-reliance and knowledge bases from villagers, and knowledge support from professionals available from outside the village.

When international sustainability assessment methods were first introduced, the concept of 'sustainability' was perceived as a new western idea that could be adapted in the Chinese context. Whilst the concept of 'sustainable design' as a newly translated phrase from English can contribute to inspire Chinese thinking and help to introduce systematic methods for sustainable design and construction; the knowledge of 'sustainability' should not be considered as a totally new imported idea, but one that has its roots and knowledge base in historical change evident in various places (Pitts, Gao, 2014). Lessons can be learnt from previous experience. In cities, the knowledge bases in the past had rather different impacts on development. Chongqing city as a case study will be discussed in the following section.

Urban development in cities

The early central planning system in China had little influence from market forces and as a result the city's social space characteristics were homogeneous and balanced during the 1950s and 1960s. During this period, learning from the architectural approaches favoured in Russia to develop 'socialist content and national styles', the main representatives of important public buildings in different regions were large pitched roofs with monumental scale. With limited materials and funding, however, only small scale constructions were built for general public buildings and the design and construction largely relied on the locally available materials. Building design initially took account of the local climate and topography though during the Cultural Revolution period from the 1970s to the 1980s, there was very limited construction activity. Despite this, architects in different regions had tried to understand and incorporate regional traditions within the given economic conditions. In the context of scarcity of resources, the buildings for those periods were characterized by simple economical design. Pragmatic methods were adopted for regional architectural design and the methods which were known from experience to function adequately in traditional designs were favoured.

One design element here does have better environmental design outcomes, for example, internal courtyards were used in public buildings, learning from traditional houses, to create forms that were not only consistent with tradition but also improved natural lighting and ventilation, and created fluid spaces. Over these periods, in an endeavour to produce regional, national, and indigenous buildings, architects designed with common characters to suit local topography, geomorphology and climate. In this they would make use of local materials, low energy and simple construction methods; in so doing, they also inherited traditional forms and styles, and employed technical, cultural and intellectual methods that were able to provide inexpensive buildings. Similar to the rural areas where shared knowledge bases of farmers in a village have evolved in relation to new materials and technologies, in cities, one of the traditions has been followed is the way to distribute knowledge of good practice. Very often good design prototypes and requirements were promoted as examples for others to follow in the region. This was done by organising design competitions to identify premier design solutions and these were followed by local government policies and planning strategies for enforcement. The mass production methods proved to be efficient to create change, however, rapid developments also led to problems. Limited numbers of rather simplified working models were applied to a whole region, and many of the models lacked consideration of the diversity of the local conditions and were not linked to the preference and local knowledge of the user groups. The rapid urbanization since the 1990s in China has encouraged numerous examples of large-scale construction development in cities, and this has resulted in more varied and sometimes less satisfying quality of buildings and urban spaces.

Urban changes in Chongqing

Taking Chongqing as an example; the city is surrounded by mountains and defined by the confluence of two rivers: the Yangtze and Jialing Rivers pass through the city, and this forms four terrains inside the city. Due to the limits of the land capacity, buildings built along the hillsides have created the strong visual characteristics of the city (Figure 3). During the period of rapid urban development, many small lanes and steps which used to run up and down the hills have been erased, together with the small houses built on either sides of the steps.

Instead, high rise buildings, large shopping centres, and offices buildings have been constructed along wide new roads that are only suited for car transport.

Figure 3. Buildings along the sloping land in Chongqing, photo by Guo Chen.

Scholars argue that the original small and irregular layout of the public space and vernacular houses reflected the beneficial diversity of urban social life (Yang, 2017). For example, historically houses situated by the river banks and built for working class people were constructed with floors supported by stilts from the lower lying land. Those houses were called Diaojiao Lou (stilt houses) and have been promoted as the representation of local regional buildings. The earliest Diaojiao Lou can be traced back to the Eastern Han Dynasty. Most existing Diaojiao Lou were built in the 1940s and 1950s, however the majority of Diaojiao Lou have now disappeared. As timber structures, those houses could not last long without maintenance and renovation. In 2005, a new commercial street was built to learn from the traditional elevated street form (Liu, 2002), despite building from concrete, its visual forms are similar to the Diaojiao Lou's elevated floors, for visitors to experience the sensation of a pedestrian in the air (Figure 4). A contradiction exists however as those new buildings function as contemporary commercial streets that do not involve the traditional social networks.

Figure 4. Hongya Dong shopping center in Chongqing, photo by Guo Chen.

The phased programmes found in modern design and building schedules also led to separate knowledge bases between designers, manufactures and builders. In the field study in Chongqing, it was found that within a relatively short period of post occupancy period, a relatively large percentage of renewable facilities or materials failed or were changed. For example, plants died on green walls due to the failure of the watering system. It may be easier to design to incorporate new innovative ideas and technologies to meet sustainable requirements, but it takes a much longer period for the construction and manufacturing sectors to gain sufficient knowledge and experience to design and built for the local realities.

Consumers also based decisions on their knowledge and experience to choose and maintain energy saving products.

Different provinces have their own green building assessment criteria for supporting and developing green buildings based on local realities. The “Evaluation Standards of Green Buildings in Chongqing” was published in 2009, to be implemented from 2010. It required that all new public buildings invested in by government must comply with the Green building standard from 2014. However, despite the significant increase of new green buildings, they still account for a small percentage compare to the overall increase of the building sector in Chongqing. To help explain further the situation it should be understood that when the concept and theories of sustainable design were first introduced to China from the West, they were perceived as a new design movement. The general public associated ‘sustainable buildings’ with higher cost because of the better living standards they provided. It is often perceived that higher cost of sustainable buildings may be paid by developers whereas the long-term benefits are considered to go to occupants. Therefore incentive and mandatory regulations are needed to encourage stakeholders. However, this does not mean that previous knowledge from regional design needs to be sacrificed for financial reasons. Traditional regional buildings respected the site condition, took care of daily lives, habits and rituals; various design and plan strategies were also employed to reflect, respect and represent the diversity in the social life of inhabitants. Rather than create a ubiquitous form of large scale skyscrapers and public space, designers and developers can benefit from the past experience. Appropriate use of small neighbourhood divisions and verying building types could be used to enhance the characteristics of the site and community memory, and reflect prevalent diversified society.

Conclusion

This paper has examined some of understandings derived from cultural and social studies of rural settlements of Yunnan and also identified the urban heritage in Chongqing City, which highlighted the importance of knowledge bases that communities and individual had regarding what is called “sustainable development” today.

In rural areas of Yunnan Province where agriculture still provides the primary income for villagers and traditional social networks in villages are relatively intact, the classification of houses derived from the studies of the ethnic groups in the 1950s and 1960s provides knowledge bases for local government policy and planning strategies. Shared local knowledge within the rural communities could be described as a cohesive form of local knowledge capital.

In Chongqing city, before the 1980s, the planning economy system in China and the scarcity of the resources led to economical architectural design and construction methods that suited the local conditions. However, after the 1990s, a large number of building designs in urban areas focused more on the visual and size impacts than on sustainable design methods. At the same time, the concept and theories of sustainable design were perceived as a new design movement introduced from the West, and as a result were often associated with higher costs and luxury living.

This study examined the knowledge distinguishing between designers and builders and between designers and users. Field studies in both villages and cities in China demonstrate that it may be easier to design to incorporate innovative ideas and technologies to meet sustainable criteria requirements, but it takes a much longer period for the construction and manufacturing sectors to gain sufficient knowledge and experience to design and built for the local realities. Consumers also have preferences and influence actions to accept lifestyles impacting on energy use following knowledge gathered in the past. The combined planned economy and the market economy systems in China therefore requires integrating with the knowledge capital, along with other aspects of environmental and technological awareness in order to gain understanding provided from historic cultural and social studies of regional buildings. Therefore it is argued that the social and cultural aspects of 'sustainability' should not be considered as a new initiative, but one that has had its roots in the historical changes of build environments which have occurred in specific places. The social and cultural indicators for sustainable assessment methods can therefore be identified and constructed from studies of the historical transformation of the place.

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Hydrothermal Performance of a Stone Masonry Wall in a Traditional Building in Cyprus

Chryso Heracleous[1], Ioannis Ioannou[2], Maria Philokyprou[1] and Aimilios Michael[1]

[1] Department of Architecture, University of Cyprus, Nicosia, Cyprus, echryso@ucy.ac.cy
[2] Department of Civil and Environmental Engineering, University of Cyprus, Nicosia, Cyprus, ioannis@ucy.ac.cy

Abstract: The external environmental conditions have an important effect on the thermal performance and durability of the building envelope. This study, which constitutes part of a multidisciplinary research program dealing with the environmental behavior of traditional buildings in the urban center of Nicosia, Cyprus, aims to investigate the hydrothermal performance of an external stone masonry wall of a listed traditional building. For the purpose of the present research, in-situ long-term monitoring was carried out. The monitoring included the indoor and outdoor environmental conditions of a southwest oriented room situated towards the street; furthermore, the west wall of the room was monitored with temperature/moisture probes installed at various locations along its thickness and height. The experiment was complemented with laboratory measurements of the thermophysical (thermal conductivity, porosity, and sorptivity) properties of the main masonry material, i.e. a local highly porous and absorptive calcarenite. Rising damp height, time of wetness, thermal inertia and decrement factor were calculated based on the laboratory and in-situ measurements. The results were analysed in terms of existing standards and analytical equations. The calculated time lag for a period of 24 hours was estimated at approximately 4 hours; however, in situ monitoring allowed the investigation of time lag for a period of 72 hours, showing that this was approximately 28 hours. The height of rising damp was estimated at 4 m and the mean residence time for the movement of water through the wall at 85 days. These results may be used to evaluate the overall thermal performance of the building and the durability of the masonry wall under investigation. They may also prove useful in future relevant studies.

Keywords: stone masonry wall, historic building, hydrothermal performance, time-lag, rising damp

Introduction

Energy efficiency and humidity have a significant importance in building science. Various studies focus on the effects of heat, air and moisture distribution in buildings, as well as on indoor air quality and human comfort (e.g. Holm 2008, Philokyprou et al. 2013). Traditional buildings have proved to be robust, durable and adaptable due to a series of environmental design strategies adopted in vernacular architecture (Oikonomou and Bougiatioti, 2011). One such environmental design strategy relates to the thermal inertia of traditional building materials, which contributes to a delay in heat transmission and to the restriction of temperature deviations between the external and internal surfaces of the building envelope; thus, establishing more stable indoor thermal conditions and consequently reducing the annual energy demand (Ferrari 2007, Orosa and Oliveira 2012, Martin et al. 2010). However, water movement and humidity in masonry walls affect the thermal performance of the building envelope and are important controlling factors of material deterioration. Therefore, understanding moisture movement is critical for assessing the durability of a structure and for establishing effective heritage conservation.

This study, which constitutes part of a multidisciplinary research program dealing with the environmental behavior of traditional buildings in the urban center of Nicosia, aims to investigate the hydrothermal performance of an external stone masonry wall in a listed traditional building located in Nicosia, Cyprus.

Methodology

With the purpose of studying the hydrothermal performance of the masonry wall under study, in-situ long-term temperature/moisture monitoring along its thickness and height were carried out from October 2014 to December 2015; these were complemented with laboratory measurements of the main building material of the stone wall. The building under study is constructed of 50 cm thick stone masonry walls with rubble infill. The stone is a local calcarenite or unsorted biosparite quarried from the Pliocene-age Nicosia Formation (Modestou et al., 2016). It has a large average grain size and it is very loosely cemented with sparry calcite matrix resulting in a coarse, friable texture. The western wall of the building, near its southwest corner, was chosen for the placement of temperature/moisture probes, as this wall was more exposed to the external environmental conditions (Fig. 1a).

Laboratory measurements and calculations

For the determination of the thermophysical and hydro properties of the local calcarenite i.e., the main building material of the wall under study, a specimen with dimensions 20 x 20 x 3 cm was selected. The thermal conductivity (λ) and specific heat capacity (Cp) of the sample were measured using the ISOMET 2104 instrument. Thermal diffusivity (α) was further calculated as a function of the above properties and density (ρ), according to the following equation:

$$a = \frac{\lambda}{\rho \mathrm{Cp}} \qquad \text{(eq.1)}$$

Its open porosity was estimated using the method described in EN 1936; this implies saturation with water under vacuum. The water sorptivity was measured following the method described in Hall and Hoff (2012). Table 1 summarizes the thermophysical properties of the local highly porous and absorptive calcarenite.

Table 1. Thermophysical properties of the stone material

Density ρ (kg/m^3)	Thermal Conductivity λ (W/mK)	Specific heat capacity Cp (kJ/kgK)	Thermal diffusivity a (m^2/s)	Open porosity (%)	Sorptivity ($mm/min^{1/2}$)
1555	0.538	0.887	$3.91x10^{-7}$	42.3	7.09

In order to evaluate the thermal inertia effect in the high porosity stone masonry wall and its effectiveness in reducing energy demand, two dynamic indicators, i.e. the time lag and decrement factor, were used. These are very important characteristics to determine the heat storage capabilities of any structural element. Time lag represents the time that a heat wave needs to spread from the outer to the inner surface, whereas, the decrement factor shows the decreasing ratio of its amplitude during heat transmission. Several studies focus on the estimation of these factors using numerical methods (Asan 2006, Stephan et al. 2014, Collet et al. 2006). The time lag (φ) and decrement factor (f) in this study were therefore calculated using the following equations proposed by Asan (2006):

$$\varphi = \begin{cases} \tau\,(Tsi_{max}) - \tau\,(Tse_{max}) & for\ (Tsi_{max}) > \tau\,(Tse_{max}) \\ \tau\,(Tsi_{max}) - \tau\,(Tse_{max}) + P & for\ (Tsi_{max}) < \tau\,(Tse_{max}) \\ P & for\ (Tsi_{max}) = \tau\,(Tse_{max}) \end{cases} \quad \text{(eq. 2)}$$

$$f = \frac{Asi}{Ase} = \frac{Tsi_{max} - Tsi_{min}}{Tse_{max} - Tse_{min}} \quad \text{(eq. 3)}$$

where Tsi_{max} and Tse_{max} are the times when the interior and exterior surface temperatures respectively reach their peak value within a period of 24 hours.

For the calculation of the steady state height of rising damp the equation proposed by Hall and Hoff (2012) was used:

$$hss = S\,(\frac{b}{Ne\theta w})^{1/2} \quad \text{(eq. 4)}$$

where hss (mm) is the height of rising damp, b (mm) the thickness of the wall, S ($mm/min^{1/2}$) the sorptivity, θw the volume fraction porosity of the material, e (mm/min) the evaporation rate and N the sides of the wall exposed to evaporation (set at 2 for evaporation from both sides).

The mean residence time for the movement of water through the wall was calculated using the following equation (Hall and Hoff, 2012):

$$t95 = \frac{3b\theta w}{Ne} \quad \text{(eq. 5)}$$

In situ monitoring

The variation of temperature was measured along the height and depth of the wall section; humidity was investigated along its height alone (Fig. 1b). The temperature sensors were nickel alloy type K thermocouples connected to a multi-channel data logger (PicoLog TC-08) which was activated every 10 minutes for a second. These were installed sideways at various locations along the thickness of the stone, i.e. at 0, 2, 25, 50 and 100%, at a height of 80 cm, as well as along the wall's height at 15, 30, 60, 80, 100 and 120 cm above the street level. Moreover, a thermocouple was installed on the outer wall surface, in a position that was protected from direct sunlight (P7/Ext.) (Fig. 1c). Good adhesion of the sensors to the wall was ensured through the use of elastic rubber, thus preventing thermal bridging. For moisture measurements, insulated stainless steel pins connected with two resistance-type moisture sensors (ceramic pins) were used and connected to a multi-channel data logger (ADC-20/ADC-24). These sensors were mounted on the inner surface of the wall in positions extending up to 120 cm from the floor level, as shown in Figure 1b. The moisture sensors were connected to a data acquisition system, which was automatically activated every 10 minutes for a duration of 5 seconds. The average of 5 individual measurements was calculated discarding the first and last measurement.

The exterior weather conditions were monitored with a 30-minute sampling frequency, using a weather station (Davis Vantage Pro2) installed at about 2-3 meters above the roof of the building under investigation. Interior air temperature and humidity levels were also recorded at a height of 1.5 meter in the middle of the room, to avoid thermal convective effects of walls, using calibrated EL-USB-LCD data loggers.

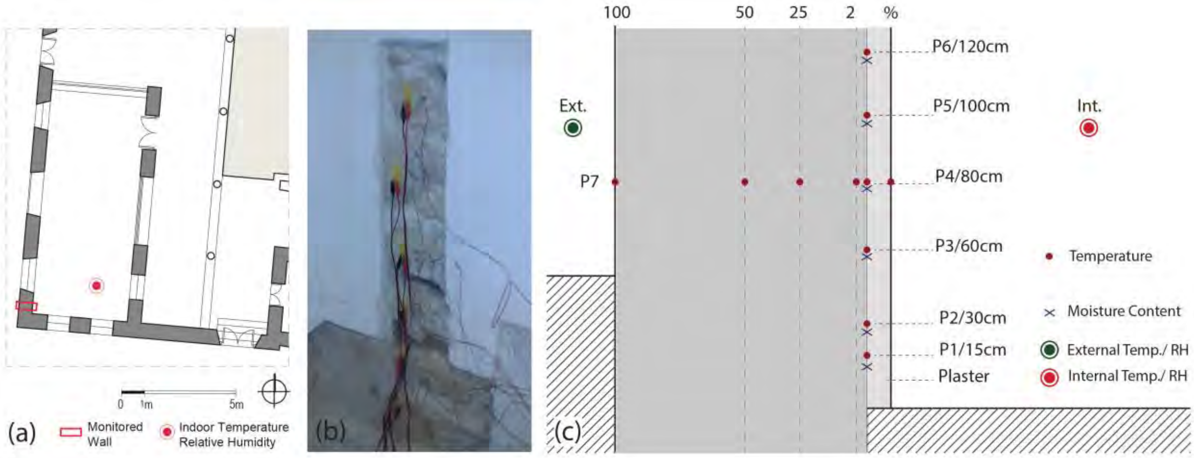

Figure 1. (a) Plan of the building under study (b) In situ monitoring (c) Sensors layout in the stone masonry wall

Results and Discussion

Wall thermal behaviour analysis

In the framework of the current research, the dynamic effect of thermal mass was estimated, analyzing the in-situ monitoring temperature data along the thickness and height of a stone masonry wall. For the calculation of the dynamic indicators, the position P5/100 cm was selected, since this was expected to be less affected by rising damp. Selected results from the cold period associated with rainfall events (early February 2015), intermediate period after rainfall events (early March 2015) and warm period without rainfall events (late May 2015) are hereby presented. The average values and standard deviation of the indicators calculated according to aforementioned equations are shown in Table 2.

Table 2. Average and standard deviation of experimental time lag and decrement factor

Period	Description	Time lag ϕ (h)	SD	Decrement factor f (-)	SD
29.01-15.02.2015	Rain Stable temp. 29.01-08.02.15 Temp. drop 09.02-15.02.15	4:40	2:45	0,113	0,057
01.03-10.03.2015	No rain Stable temp.	3:27	1:46	0,13	0,119
15.05-28.05.2015	No rain Temp. rise 15.05-20.05.15 Stable temp. 21.05-28.05.15	3:45	1:01	0,1	0,021

As observed, time lag values vary depending on the particular weather conditions i.e. raining events, wind velocity, solar radiation, relative humidity, and rapid temperature change. During the period when the temperature was stable (21.05-28.05.2015), the maximum internal surface temperature Tsi_{max} occurred around 18:30, while the maximum external surface temperature Tse_{max} occurred around 14.30. This indicates a time lag of approximately 4 hours within a period of 24 hours. The decrement factor was estimated at 0.1 and it is in line with the value reported by Asan (2006), who states that wall thicknesses above 30 cm show decrement factors near zero. The results are also in line with other studies which evaluate the thermal inertia of stone buildings, such as the research of Stephan et al. (2014) which demonstrates a time lag of 4 hours and a decrement factor of 0.1. However, in situ monitoring allowed the investigation of time lag for a period of 72 hours, showing that this was approximately 28 hours, i.e. 4+24 hours (comparison between P5/100 cm and P7/Ext. in Fig. 1c). The standard deviation of the time lag was estimated at 1 to 2 hours in no rainfall periods; whereas during rainfall events this increased to about 3 hours. Larger variations of time were observed in the minimum values.

Figure 2 depicts the temperature flux through the wall under investigation, at all monitoring locations, for a period of 5 days in May 2015. During that period, a steep decrease of external temperature, followed by a steady increase, allowed some interesting observations to be derived. Looking at the time when the maximum temperature occurred along the thickness of the wall, starting from the external surface (P7/Ext.) towards the interior (4, 4c, 4d), the following is observed: T_{se_max}≈14:30, $T_{si50\%\_max}$≈23:30, $T_{si25\%\_max}$≈23:30; whereas, $T_{si0\%\_max}$ occurred at around 18:30. The correspondence of the time when the heat wave hit every internal position in relation to the exterior shows that the peak is observed on the following day. It is interesting to note that the internal surface $T_{si0\%\_max}$ achieved its peak temperature value earlier than the sensors at 25% and 50% monitoring locations. This is attributed to the effect of ventilation from the *arseres* i.e., clerestories, which were always open during the recorded period, allowing the internal environment to be exposed to the external.

The calculated time lag for the sensors at 25% and 50% monitoring locations was 33 hours. It is worth mentioning that the thermocouple in position 4b $T_{si2\%}$ shows similar values with the values of the external environment. This may be the result of the placement of the thermocouple in a joint composed of a different material (possible gypsum or clay mortar); therefore, its behavior is ignored. Finally, the temperature on the plaster surface $T_{si\_plaster}$ (4pl) shows similar behaviour with the inner surface of the stone wall $T_{si0\%}$. In terms of temperature differentiation along the height of the wall, it was observed that the temperature slightly increased with height (1-2 K difference between P1/15 cm and P6/120 cm). This is the result of moisture content differentiation along the height of the wall. Earlier rainfall events (12-14.5.2015) led to an increase in the height of rising damp, thus decreasing the heat capacity of the material and consequently the temperature at those monitoring points.

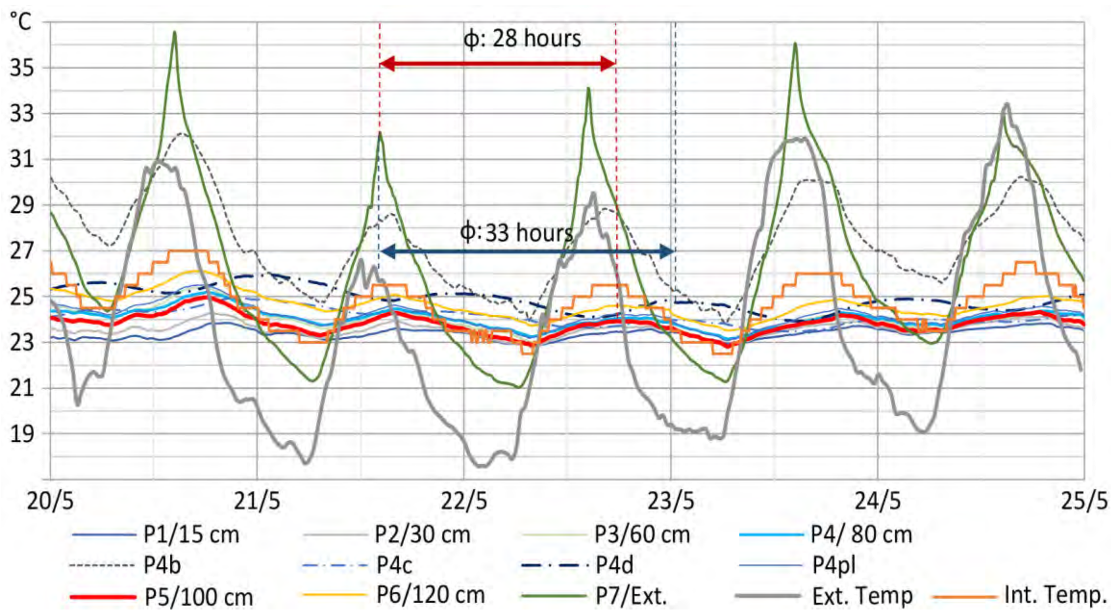

Figure 2. Hourly temperature distribution in all sensor locations during 5 days in May 2015.

Wall moisture behaviour analysis

The building under study exhibits moisture problems at significantly high levels (Fig. 3); thus, an interesting issue for further investigation was the examination of the height of rising damp and of the residence time for the movement of water through the wall.

The height of rising damp on the interior walls follows the pattern of shading line at the exterior wall (Fig. 3). In the middle of the room, around the window, this height exceeds 2.80 m; this is significantly higher than in the corner of the wall, where the in-situ monitoring had taken place. This may be a result of enhanced evaporation in the corner of the room, due to uncontrolled air flow in the junction between the two walls. Building corners and parapets are especially susceptible to wind currents, because the wind induces very steep pressure gradients in these areas (Straube, 2001). This can also be confirmed from the thermal image which illustrates increased heat losses in the corner (Fig. 3c).

Figure 3. (a) External view and (b, c) internal surfaces of the southwest room under study showing clear signs of moisture problems.

In the course of the year, the height of rising damp changes continuously in response to imbalances between the inflow (at the base of the wall) and the outflow (by evaporation at the wall surface) of moisture. Table 4 shows the effect of evaporation rate on the height of rising damp for the wall under study. The annual mean height of rise was estimated at 4 meters.

Table 4. Effect of evaporation rate on the height of rising damp

	Evaporation rate (Cox, 1999) (mm/min)	Height of rising damp (m)	Mean residence time (days)
Annual	0.0022	4	85
January	0.0007	7	267
July	0.004	3	46

In order to confirm the calculated height of rising damp, continuous moisture monitoring started in October 2014 and continued for 457 days. As observed in Figure 4, different rainfall events took place during the recorded period: short rainfall events or showers followed by a dry period of several days (e.g. 1.11.2014, 26.11.2014), long wet periods (09.12.2014-15.03.2015) and dry periods (6.6.2015-26.11.2015).

Figure 4 gives a graphical overview of the moisture content pattern in mV at 12:00 for the period of monitoring, together with the daily cumulative rainfall events. As shown, the moisture content differentiates along the height of the wall. Specifically, the wetting indicator decreases as the distance from the ground level increases, as expected (Hall and Hoff, 2012).

The area around P2/30 cm appears to be saturated at all times, as it is situated below the road level. Moisture in P6/120 cm is generally stable with low voltage, demonstrating no or little moisture content. Positions P4/80 cm and P5/100 cm show the highest fluctuations, demonstrating the effect of rising damp, and the zone where decay and salt crystallisation is expected to occur. The in-situ monitoring results are, nevertheless, not consistent with the values given by steady state calculations. According to the in-situ monitoring, the rising damp height at the area under investigation should be lower and should reach approximately 80 cm. This may be the result of increased evaporation rate at the corner.

The influence of the daily recurrent pattern of RH is reflected in the wall moisture content. In situ monitoring shows that positions P5/100 cm and P6/120 cm are directly affected from external environmental conditions portraying large variations. For example, on 21.02.2015 the external relative humidity drops to 35%, leading moisture content in positions P5/100 cm and 6/120 cm to low levels (42 and 17 mV respectively compared to the mean values of 55 and 35 mV under non-rainfall events). External RH linearly affects the drying rate of porous materials (Hall et al. 1984).

The detailed examination of the moisture changes of the wall during the period under investigation showed that, the estimated time for water to travel in position P4/80 cm was 56 days, whereas in P5/100 cm it was 90 days. The time for the desorption of position P5/100 cm was less, i.e. 55 days according to the in-situ monitoring (12.11.2015).

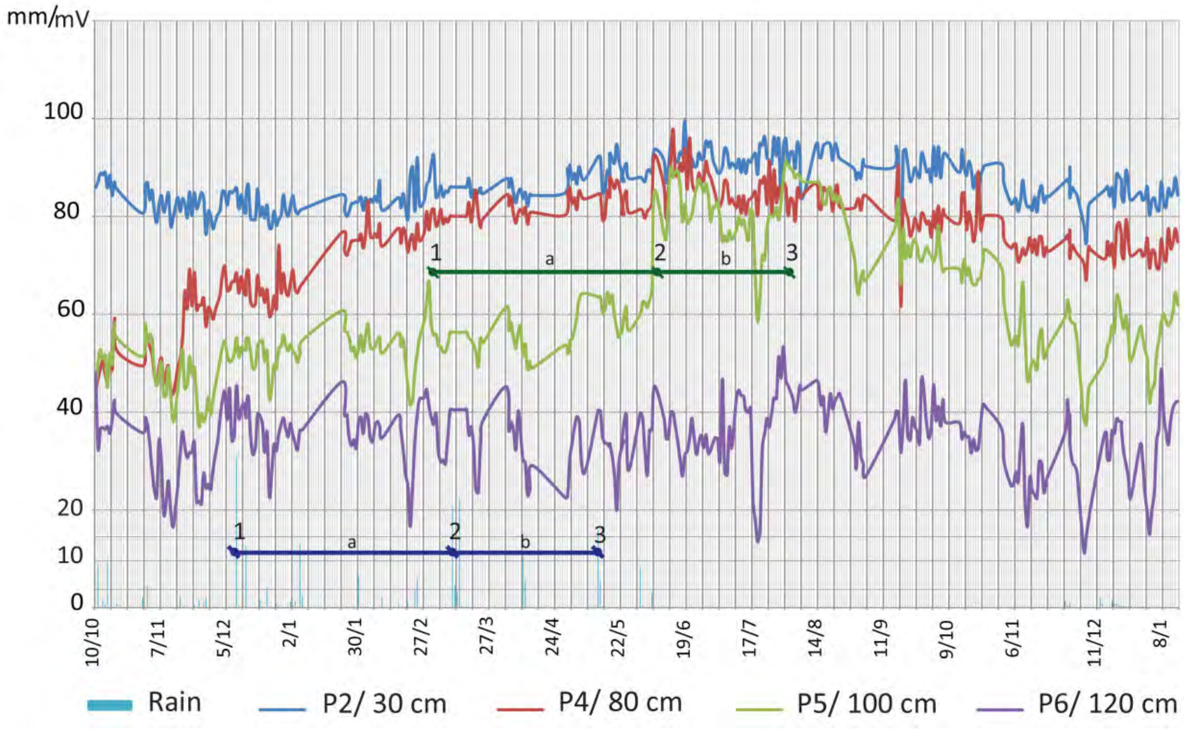

Figure 4. Graphical overview of moisture content pattern in mV at 12:00 for the period of monitoring, together with daily cumulative rainfall events.

Conclusion

Environmental conditions have a significant effect on the thermal behavior of buildings and on the durability of building envelope materials. The high time lag (28 hours) and low decrement factor (0.1) values estimated in this study confirm the thermal stability of the indoor environment of traditional stone structures. It is worth mentioning that rainfall events lead to absorption/desorption of moisture, leading to significant deviations in the thermal time lag. This shows the close relationship between rain events and absorption/desorption of moisture by stone masonry walls. The calculated height of rising damp was estimated at 4 m and the mean residence time for the movement of water through the wall at 85 days. However, in situ monitoring and observation allowed further investigation showing the dynamic effect of environmental conditions at specific areas of a building.

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Design to Thrive

Spatial and environmental delight in Northern Vietnam houses for contemporary application

Long Hoang[1] and Benson Lau[2]

[1] Institute for Building Science and Technology, Vietnam, email: duclonghoang@gmail.com
[2] Faculty of Architecture and the Built Environment, University of Westminster, London, United Kingdom, email: B.Lau@westminster.ac.uk

Abstract: Published studies suggested that the environmental design strategies adopted in vernacular houses in Vietnam are spatially flexible, environmentally efficient and well adapted to local natural and cultural context. Investigating two representative houses in Northern Vietnam, this study aims to explore the spatial delight, thermal and daylighting performances of this type of houses and assess the impacts of environmental design strategies on the thermal and visual comfort for the occupants.
Computer aided parametric analysis of the two selected houses was conducted by using IESVE to evaluate their thermal and daylighting performance. Additionally, a representative contemporary shop-house was also investigated and tested for comparative analysis. The thermal and daylighting performance of all three cases were benchmarked against relevant environmental design standards. Based on the research results, a reconceptualised shop-house was proposed and evaluated to explore the significance and contemporary relevance of the environmental design features and strategies identified in the vernacular houses.
The research findings indicate that vernacular houses in Northern Vietnam respond well to the local climatic challenges and offer desirable thermal and visual comfort. Moreover, the vernacular environmental strategies adopted in these houses can be selectively re-adapted to help improve the thermal and daylighting performance of the contemporary urban shop-house.

Keywords: spatial delight, vernacular environmental strategies, thermal comfort, visual comfort, contemporary shop-house

Introduction

Vernacular houses in Northern Vietnam, as climatically, socially, and economically adaptive accommodations, form an important architectural legacy of Vietnam (Hoang, 2013). However, there is little published holistic investigation of the thermal and daylighting performances of the vernacular housing typologies in Northern Vietnam. Most studies focused on only one housing type which does not offer a conclusive understanding of the spatial and environmental delight in these houses. Also, systematic and evidence-informed studies of the effectiveness of the environmental strategies are scarce. Furthermore, there is a need to identify and re-apply the workable vernacular environmental strategies to contemporary buildings. Lastly, the lack of workable research methodology for assessing visual comfort and irrelevant and obsolete parameters used to explore the luminous environment indicate a need for a rigorous and quantitative light study for vernacular houses in Northern Vietnam.

Research objectives and methodology

Research objectives

In this research, two research objectives were proposed: firstly, assessing the thermal and visual comfort in vernacular and contemporary housing in Northern Vietnam, and secondly, evaluating the effectiveness of the application of traditional environmental strategies in contemporary shop-houses.

Research methodology

This research was conducted based on three case studies. Each case study represented one housing typology of the following: vernacular rural house, vernacular urban shop-house, and contemporary shop-house.

The research process involved three successive stages. The first stage was to analyse the environmental design concepts and architectural features of the three cases. The second stage was to explore the environmental performances of the vernacular rural, the urban dwellings, and contemporary shop-house through computer aided simulation, computational modelling, dynamic and steady state simulations. Subsequently, the simulated data were processed and the overheating hours (OH), cooling degree hours (CDH), heating degree hours (HDH), and Useful Daylight Illuminance (UDI) were analysed. These performative assessment criteria of all test cases were compared. Furthermore, they were benchmarked against TM52, CIBSE Guide A, and CIBSE LG10. The third stage involved developing, testing, and proposing a theoretical South-facing shop-house model which embraced the workable vernacular environmental design principles and features through in-depth building performance analysis.

Typical vernacular rural house

The model for the typical vernacular rural house was nominated by Hoang (2013, p.373). Ly (2012, p. 24) also agreed that this house model was representative of rural housing in Northern Vietnam.

Spatial delight in the typical vernacular rural house

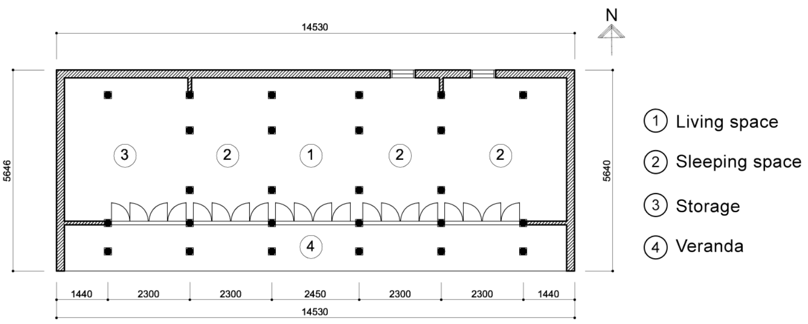

Figure 1 Floor plan of the typical vernacular rural house

The spatial layout of the typical vernacular rural house revealed a culturally and environmentally integrated architectural design (Figure 1 and Figure 2). Culturally, the spatial arrangement which places the sacred altar in the living space, at the centre of the house, honours their ancients. Environmentally, the narrow West façade helps reduce the wall surface exposed to direct sunlight during hot hours in summer while the long South façade takes advantage of the solar gain in winter and capture the South-East prevailing wind.

The high roof and large open doors enhance buoyancy-driven ventilation and keep the indoor spaces cool at night. In addition, the steep slope of the roof helps discharge water quickly. Another important feature of this type of house is the roof overhang. It provides shading, acts as a buffer space between the inside and outside and permits desirable indirect light to lit the living spaces and direct solar gain in winter.

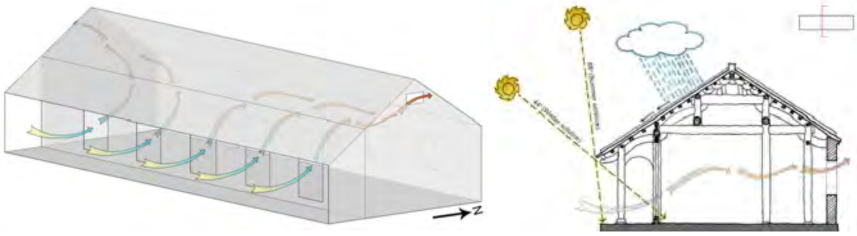

Figure 2 Buoyancy-driven ventilation in the vernacular rural house

Thermal performance in the typical vernacular rural house

Table 1 **Error! Reference source not found.**shows that the indoor thermal condition in the rural house is not thermally acceptable in summer. Overall, thermal comfort is achieved for 67% of the typical year.

Table 1 The simulated percentage of OH and daily CDH against CIBSE Guide A and TM52

	CIBSE Guide A	TM52	Simulated figure
Percentage of overheating hours (%)	< 1	< 3	16.3
Maximum daily CDH (degree hours)	Not specified	< 6	41
Percentage of underheating hours (%)	Not specified	Not specified	17

The predicted OH and CDH during most occupied hours (Figure 3) were much lower than the overall values. This suggests that the main objective of the vernacular rural design was to increase night cooling and prioritise nocturnal thermal comfort.

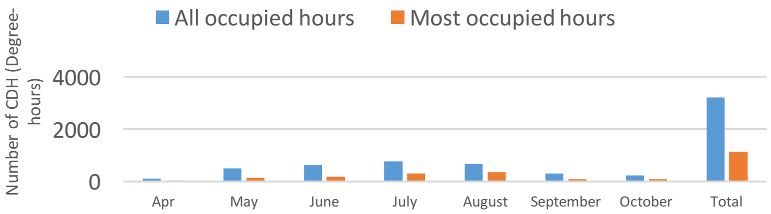

Figure 3 Cooling degree hours in total and in most occupied hours

Daylighting performance in typical rural house

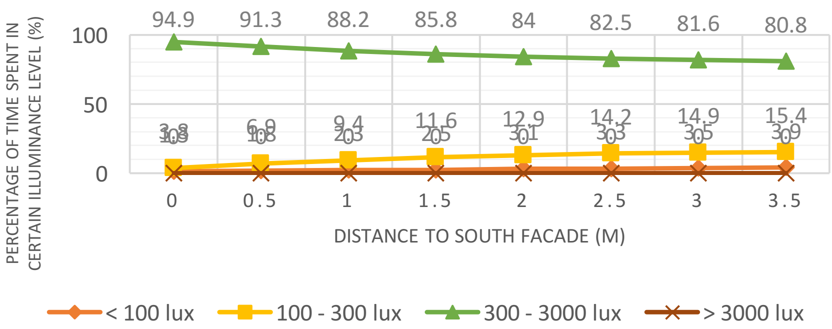

Figure 4 UDI by distance to main doors (Thresholds derived from CIBSE LG10)

The daylighting performance of the typical rural house is acceptable. Considering the UDI of the living space and the criteria of CIBSE LG10, the typical vernacular rural house was well-lit. Most points on the working plane achieve at least 80% of its occupied time with illuminance from 300 to 3000 lux (Figure 4).

Typical vernacular urban house

The old house at 87 Ma May Street was selected to represent vernacular urban housing for this research after a background study of the history of housing in Hanoi. Residences built in Hanoi before the 19th century retained typical local architectural features (Tran, 2008). Drawing an agreement with this claim, other authors emphasised that only shop-houses constructed in Hanoi Old Quarter before or in the 19th century should be considered purely vernacular (Management Board of Hanoi Old Quarter Heritage, 2014). The selected house was built in Hanoi Old Quarter in the 19th century. Thus, it is representative of Northern Vietnam traditional urban houses.

Spatial delight in the typical vernacular urban house

The spatial arrangement and floor plans of the old house at 87 Ma May Street are shown in Figure 5.

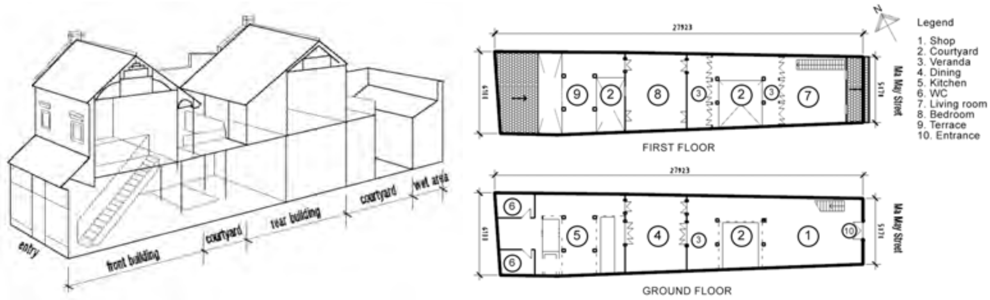

Figure 5 Spatial arrangement of the House at 87 Ma May, Hanoi (Ly, 2012)

This house inherits some design features from the vernacular rural house, which include large opening doors, high and steep roofs, and verandas. The steep roof slope helps to control and discharge rainwater. The veranda creates a larger buffer zone shielding the living room and bedrooms from solar heat gain. The stack effect induced by the high ceiling and large openings enhance cross ventilation and night cooling strategies (Figure 6).

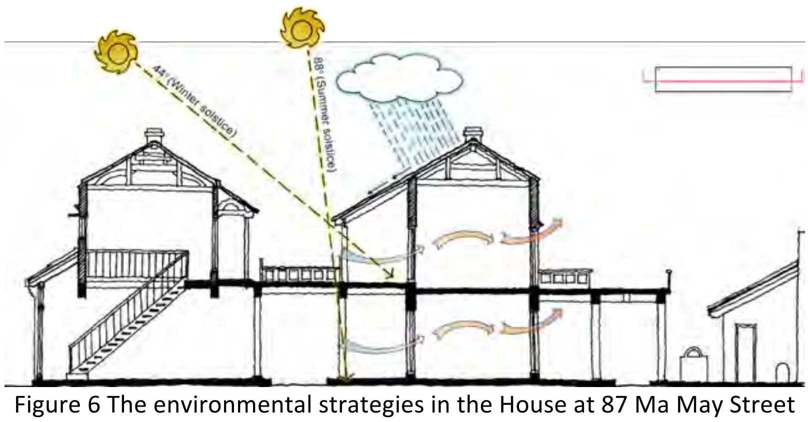

Figure 6 The environmental strategies in the House at 87 Ma May Street

Unlike the rural house, the urban house must accommodate both external and internal activities. Responding to this need, the builders applied a courtyard-centred layout. The courtyards allow cooler air to be supplied to main living spaces. Furthermore, they are the main sources of daylight and fresh air.

Thermal performance in the typical vernacular urban house

The traditional urban shop-house confirms the significance of night cooling in vernacular dwellings in Northern Vietnam. The large controllable openings to the internal courtyards can be closed during daytime and opened at night to benefit from night cooling. The percentage of OH and maximum daily CDH (Table 2) indicated that all rooms did not meet the requirements of TM52. Nevertheless, while the daily occupied time of the bedroom was 4 hours longer than the occupied time of the living room, the CDH of the living room surpassed the figures for the bedroom by vast margins (Figure 7). This supports the observation found in the rural house that vernacular environmental designs in Northern Vietnam focus on nocturnal thermal comfort rather than diurnal comfort.

Table 2 Percentages of OH and maximum CDH of main rooms in the House at 87 Ma May

	TM52	Living room	Main bedroom	Shop
Percentage of overheating hours (%)	< 3%	27.1	8	28.9
Maximum daily CDH (degree hours)	< 6	34	14	36

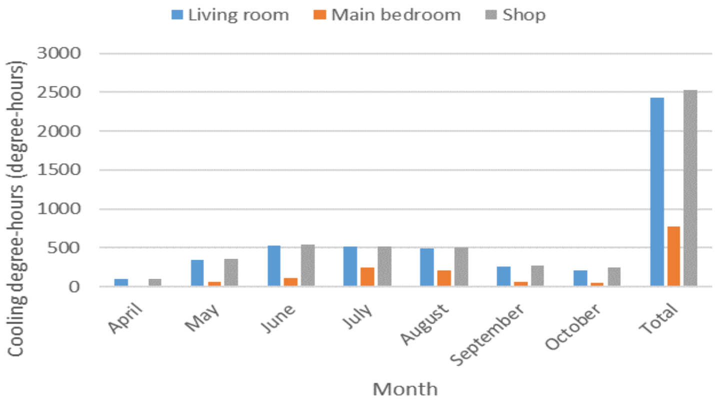

Figure 7 Number of CDH for different rooms in the House at 87 Ma May Street

Daylighting performance in the typical vernacular urban house

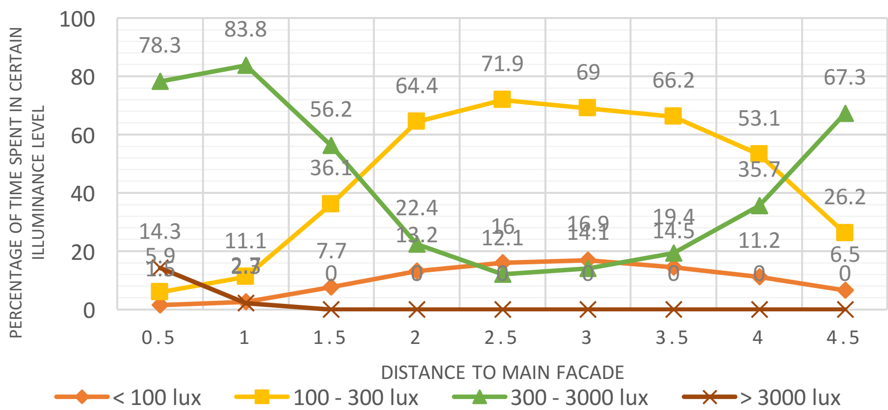

Figure 8 UDI in the living room of the House at 87 Ma May by distance to the main facade

The living room in the vernacular urban house shows a sophisticated daylighting strategy. Small windows on the South-East façade reduce undesirable solar ingress while the large openings to the courtyard ensure adequate daylight illuminance throughout the day. Most points on the working plane will experience the illuminance of 100 – to 3000 for 83.1% to 98% of the occupied time in a typical year (Figure 8).

Typical contemporary shop-house

Architectural features

The contemporary shop-house was selected for investigation due to its functional similarity to the vernacular urban house as shown in Figure 9. Spatially, it has the typical shop-house's rooms: shop, three bedrooms, two living rooms, a kitchen, and a veneration room.

Thermal performance in the typical contemporary shop-house

The percentages of overheating hours and underheating hours of main living and working spaces (Table 3) in the contemporary shop-house indicate that no room met the TM52 requirements. Thermal comfort in the contemporary shop-house is not achieved.

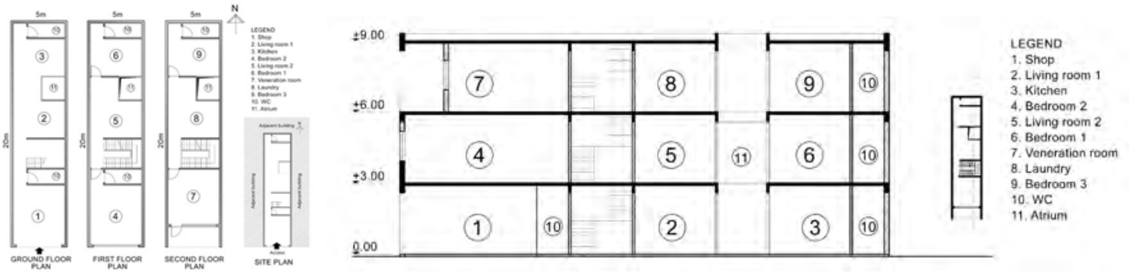

Figure 9 Floor plans, site plan, and longitudinal section of the typical contemporary shop-house

Table 3 Percentages of OH, UH and maximum daily CDH of the contemporary shop-house

	TM52	Living room 1	Living room 2	Bedroom 1	Bedroom 2	Bedroom 3	Shop
Percentage of overheating hours (%)	< 3%	3.1	1.2	8.4	15.3	12.4	31.9
Maximum daily CDH (degree hours)	< 6	2	11	6	14	11	30
Percentage of underheating hours (%)	unspecified	19.6	19.3	20.8	17.3	20.4	18.7

Daylighting performance in the typical contemporary shop-house

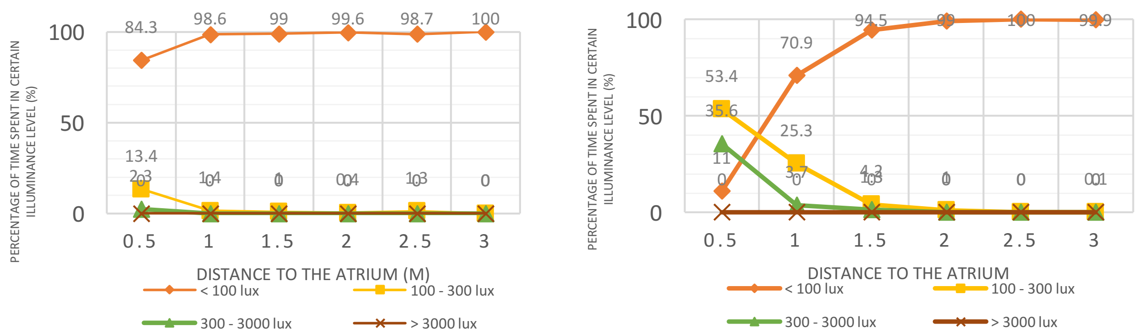

Figure 10 UDI of the living room 1 of the contemporary shop-house

The daylighting performances of the two living rooms are generally poor. Their working planes were predicted to receive less than 100 lux for 70 - 99% of the year (Figure 10).

Reconceptualised shop-house model

Spatial delight in the reconceptualised shop-house

Figure 11 Floor plans and environmental strategies of the proposed shop-house model

Based on the results of the previous case studies, a reconceptualised model is developed to respond better to occupants' spatial and environmental needs. This new model has only one living room on the first floor. The living room is exposed to the main street so that it can gain access to more natural light. All bedrooms, shielded by overhangs, are situated further away from the main street than the living room. Single-sided and cross ventilation and daylighting are allowed by properly sized windows and internal courtyards. The environmental strategies of the reconceptualised shop-house are illustrated Figure 11.

Thermal performance in the reconceptualised shop-house

The new proposed model clearly outperforms the contemporary one in terms of energy consumption and thermal comfort because of the combined outcome of all the applied vernacular strategies. Noticeably, there is a wide disparity of over 5000 heating degree hours between the proposed model and the contemporary one (Figure 12).

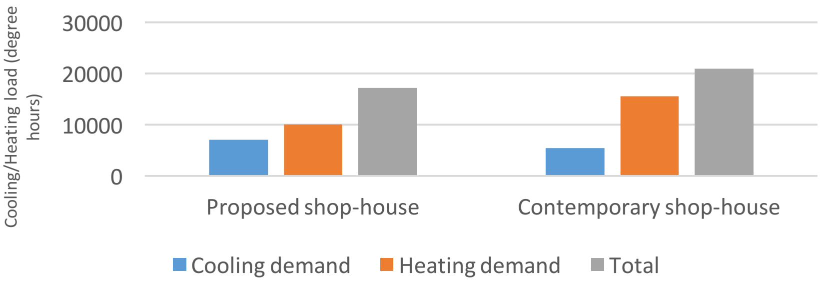

Figure 12 Heating and cooling degree hours of the contemporary and reconceptualised shop-houses

Except for bedroom 1, the cooling degree hours of bedroom 2 and 3 in the proposal are far lower than the contemporary bedroom demands. A similar observation is obtained in the heating degree hours (Figure 13).

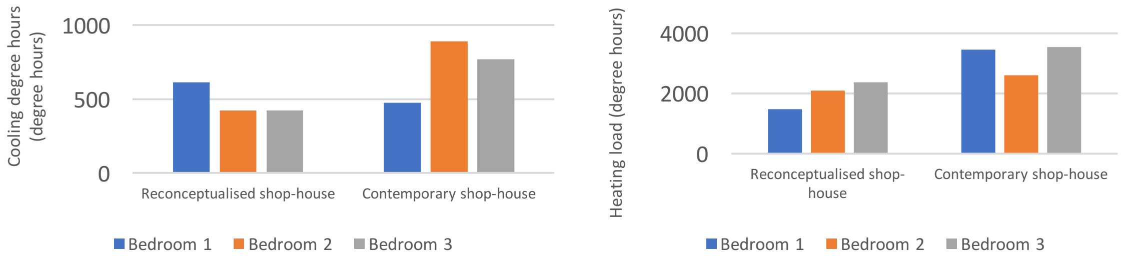

Figure 13 Cooling and heating degree hours of bedrooms in the proposed and contemporary shop-houses

Daylighting performance in the reconceptualised shop-house

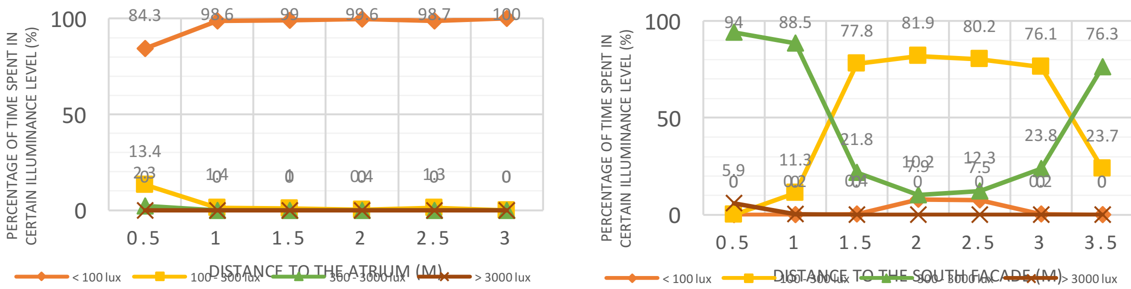

Figure 14 UDI of Living room 1 in the contemporary shop-house (right) and the reconceptualised one (left)

The daylighting performance of the proposed shop-house is much better than that of the contemporary house. The living room of the proposed house is predicted to benefit from acceptable (100 – 300 lux) or desirable (300 – 3000 lux) illuminance for 80% to 90% of daylight hours (Figure 14).

Conclusion

Environmental design strategies in vernacular housing in Northern Vietnam

The Environment design features identified in the vernacular housing in Northern Vietnam presents a workable approach to achieve the right balance between culture, functions, and human comfort. All the well tested vernacular environmental strategies, including courtyards, high-pitch roof, materials of low U-value, verandas, and window sizing, can be applied to contemporary shop-house design. The combined impacts of these solutions in a reconceptualised shop-house can be predicted to decrease about 25% of the total heating and cooling degree hours.

Application of vernacular environmental strategies in a reconceptualised shop-house

The effectiveness of vernacular environmental strategies in the newly proposed model indicates two important points. Firstly, the contemporary shop-house in Northern Vietnam can be reconceptualised into a more environmentally efficient model which not only accommodates contemporary spatial demands but also help mitigate thermal and daylighting discomfort. Secondly, vernacular environmental strategies can be further developed and re-adapted effectively to contemporary housing. However, the application may not be straightforward and would require an initial re-design of spatial arrangement and rigorous building performance analysis.

Thermal and visual comfort of housing in Northern Vietnam

As shown in the performative analysis, the typical vernacular rural and urban houses did not achieve thermal comfort. The first explanation for this phenomenon is that local builders gave more priority to heating demand than cooling. The second possible reason is that the selected standard to benchmark against might not be appropriate for the climatic conditions of Northern Vietnam.

The contemporary shop-house did not achieve thermal comfort because preventing increases in indoor temperature for thermal comfort is not sufficient in hot humid climate, and proper promotion of cooling is required.

All vernacular houses have good daylighting performance while the living rooms in the contemporary shop-house are not adequately lit. The main vernacular living spaces have good access to daylight because of the deliberately placed courtyards and large folding doors protected by extended eaves. However, the small atrium in the contemporary house does not offer many daylighting benefits.

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Performance in Passive Climate Control of Traditional Archetype at a Tibetan Monastery

Lingjiang Huang[1], Jiayu Xiao[2]

[1] Department of Architecture, Wuhan University, Wuhan, China, huanglj@whu.edu.cn
[2] Department of Architecture, Wuhan University, Wuhan, China, aling_931@126.com

Abstract: Passive measures were employed in vernacular buildings to respond to local climate. Through long-term trial and error, certain fixed archetypes were gradually formed. They are worthy to inform modern design against the local climate. This paper presents a traditional Tibetan archetype that was employed in a three-story building in the Jokhang Temple. The basic pattern of the archetype is an enclosed atrium surrounded by dormitory rooms, while a large volume of skylight projecting the roof was adopted for purposes of natural lighting, ventilation etc. A perforated floor was further employed as a horizontal opening for the lower floor. The archetype provides complex passive solutions to manipulate indoor climate against the extreme climate. However, the performance has not yet been examined. The aim of this study is to first analyse the strategies of climatic control in this archetype. Then, by computer simulation, the performance of natural lighting and ventilation are evaluated. Later, the major factors of the archetype that have impacts on the performance are discussed. At last a traditional archetype in Tibetan local climate is summarized.

Keywords: traditional archetype, passive climate control, Tibet

Introduction

Vernacular buildings provided as comfort as possible indoor thermal environment by intelligence responding to local climatic conditions. Through long-term trial and error, the intelligence was developed into design strategies and gradually formed certain fixed archetypes. Numbers of studies on vernacular buildings have been conducted from the point of view of climatic responsive designs in various types. However attention on traditional archetypes are still limited, some of which have been proved to be effective through centuries and are also worthy to inform modern designs against the local climate. This paper presents a traditional archetype employed in the most important temple in Tibet-the Jokhang Temple built in Lhasa during the thirteenth century. The archetype provides passive solutions to manipulate indoor climate against local extreme climate. However, the performance has not yet been examined. The aim of this study is to first analyse the climatic responsive strategies in this archetype. Then, by computer simulation, the performance of natural lighting and ventilation of the archetype are evaluated. Later, the major factors of the archetype that have impacts on the performance are determined.

Primary features of climatic conditions in Lhasa

Tibet is located in the southwest region of the Tibetan Plateau with an average altitude of 4000m, while Lhasa is the largest settlement in Tibet with an altitude of 3600m and belongs to the Dwd climate or cold climate according to the global Koeppen-Geiger Climate classification (Yang, 2004) (Kottek et al, 2006).Climatic features of Lhasa includes annual low temperatures, intensive and long solar radiation, high diurnal temperature variations and windy weather. The mean monthly temperature is approximately -1.0°C and the daily lowest temperature in the coldest month can reach -13°C, the mean diurnal variation in the coldest month is greater than 13°C, the global solar radiation in is 610 MJ/m2. Lhasa is very dry throughout the year, and in winter, the average relative humidity is low at approximately 26.5%.The windy season in Lhasa covers nearly half the year and extends from December to April, with the highest velocity reaching 12m/s(China Meteorological Bureau, 2005).

Basic patterns of the archetype

The archetype for large single-storey space that are generally employed in Tibetan monasteries has been studied in previous study (Huang and Deng, 2016). However another archetype for multiple storey buildings is very unique in traditional Tibetan public buildings. A typical case is found in a three-storey building in the Jokhang Temple, which historically functions as the administrative office of the Panchen Lama and the monk dormitory on the first and second floor while the ground floor functioned as the storeroom with no occupancy (Xu 2016).The basic pattern of this archetype includes an enclosed atrium penetrating the first and the second floor, of which are surrounded by unit rooms and circulation areas. The top atrium has a large volume of skylight projecting the roof while the lower atrium has a horizontal opening on the floor above. This archetype was found to be presented in two different forms with a large and small atrium respectively as shown in Figure1.

Figure1. Two forms of the archetype

The size of the skylight and the area of the horizontal opening are in direct proportion to the area of the atrium and the floor. The horizontal opening in the large atrium is covered by wood grating and the size of each hole keeps very small around 120mm that is less than a human foot. The reason for the perforated floor other than an open courtyard might result from the purpose of separating the lower and upper space for privacy while retaining the path for airflow and lighting. Conceptual models are given in Figure2.

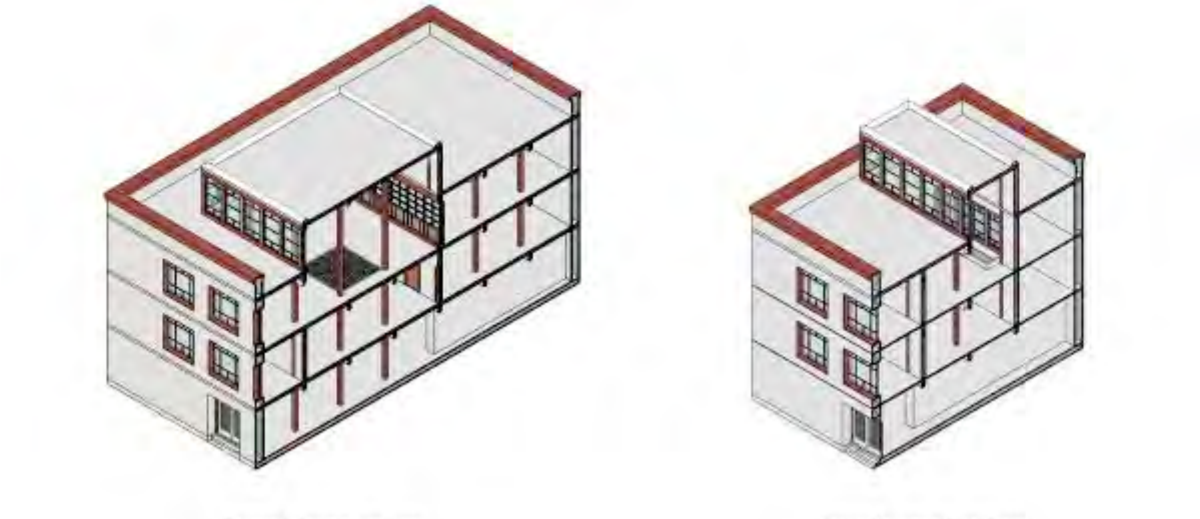


Figure2. Conceptual models of the two forms

The climate control of the archetype

Theoretical analysis

The major characters of Lhasa's climate includes low ambient temperature, high diurnal temperature variations, strong solar irradiance and windy weather, to which this archetype provides complex solutions to respond. Besides general measures of compact form and fenestration of few openings on the north side to reduce heat loss, the skylight, atriums, the horizontal opening and the entrances to the atriums forms a unique system of natural lighting and ventilation to allow airflow and light to move vertically through the building. By this system, the enclosed atrium with a skylight transforms the open space to enclosed indoor space and reduces the heat exchange with the outdoor air and heat dissipation during night. While solar irradiance is still able to be introduced inside the atrium. Natural ventilation is achieved by the way of stack effect instead of cross ventilation and avoids heat loss under windy climate. Compared with open courtyard or patio, this system provides a solution for multiple-storey buildings with large depth and width against cold and windy climate.

The skylight in this archetype has full opening to the south and also remains fully or partially open on the east and west orientation, while the north side is generally closed with solid wall. This fenestration introduces as much solar heat gain and natural lighting as possible into the indoor space. Thus the atrium on the top floor acts as a sunspace, to which the northern rooms can have side windows open for natural lighting and ventilation if necessary. The towering skylight also functions as a chimney and benefits the buoyancy natural ventilation since cross ventilation could be unavailable in the space of large depth. For the lower floor, an area of perforated floor was further employed to allow airflow and lighting through and the lower enclosed space could also benefit from natural lighting and ventilation by stack-effect. Figure3.illustrates the conceptual diagram of environment control for the case of the building in the Jokhang Temple.

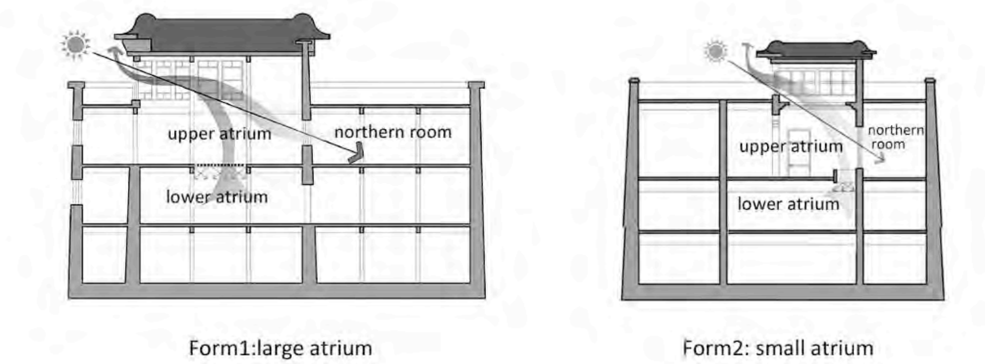


Figure3. Diagram of the two forms

Method of computer simulation

Computer simulations are further conducted to explore the above theoretical analysis. A widely used simulation tool Designbuilder was used for both natural lighting and CFD analysis. Three locations, namely the top, lower atrium and the northern room are selected for evaluation of natural lighting. As the atriums are for circulation and the northern room for office work, according to the Standard for Daylighting Design of Buildings (GB50033), the corresponding daylight factor (DF) and illuminance is required to be above values of 1 and 3, and 75Lux and 450Lux respectively in the condition of CIE overcast sky. The metric of daylight autonomy (DA) is also applied to measure the temporal and spatial distribution of the illuminance over a period of a year in the condition of real climate. As for the evaluation of natural ventilation, the status of airflow at 12:00PM on December 22nd will be simulated to explore the air velocity and airflow direction in this archetype on a typical winter day. The simulation mode is set to natural ventilation and no heating/cooling, the air change rate is set as 1 ac/h, and the other boundary conditions including air temperature, surface temperature, airflow in and airflow out are simulated in advance based on Lhasa' weather data sourced from the China standard weather date.

Results of computer simulation

The simulation results of natural lighting are displayed in Figure 4a and 4b. In Form1 of the large atrium, it can be seen that 49.6% of the area has the DF value over 1, and the DA shows that 90.1% of the area meets the requirement of illuminance for two third of a year. For the lower atrium, only 1.63% area has the required DF value, but 17.2% of the area has the required illuminance for half of a year. As for the northern room with a side window, 10.5% of the area meets the DF requirement, while only 0.77% of the area has adequate illuminance for half of a year. As for Form2 of the small atrium, in the upper atrium, 52.5% area has the DF over the value of 1, while DA value shows that 99.1% of the area meets the requirement of illuminance for half of a year. For the lower atrium, the highest value of DF is 0.63 and no area can meet the requirement of DF. However, DA value shows that nearly 10% area underneath the perforated floor meets the requirement of illuminance for more than half of a year. As for the northern room, 33.5% area meets the requirement of DF, and only 5.5% area has the DA over 50%.

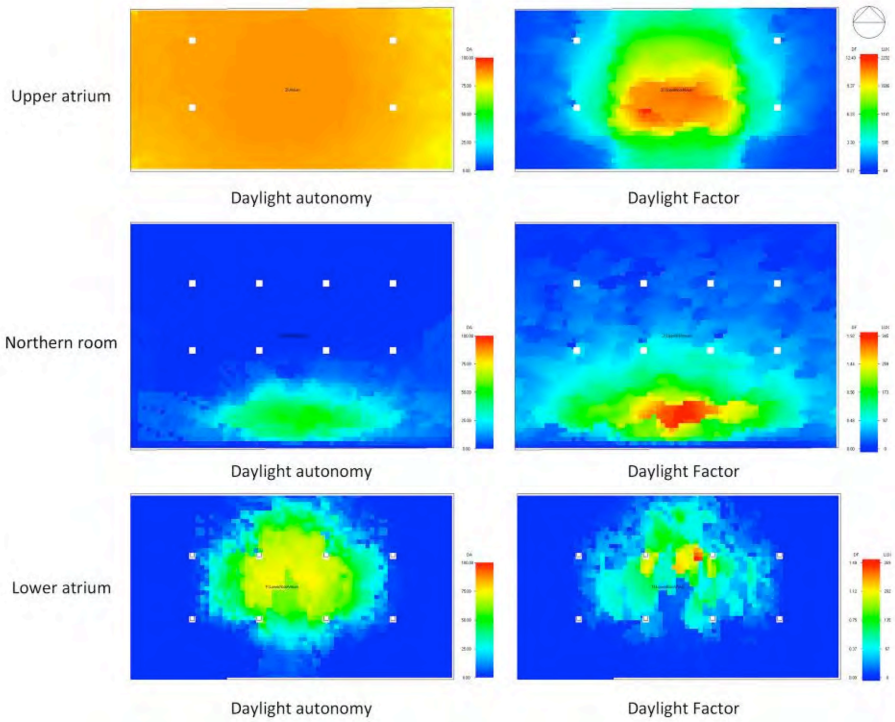


Figure4a. Natural lighting in Form 1:large atrium

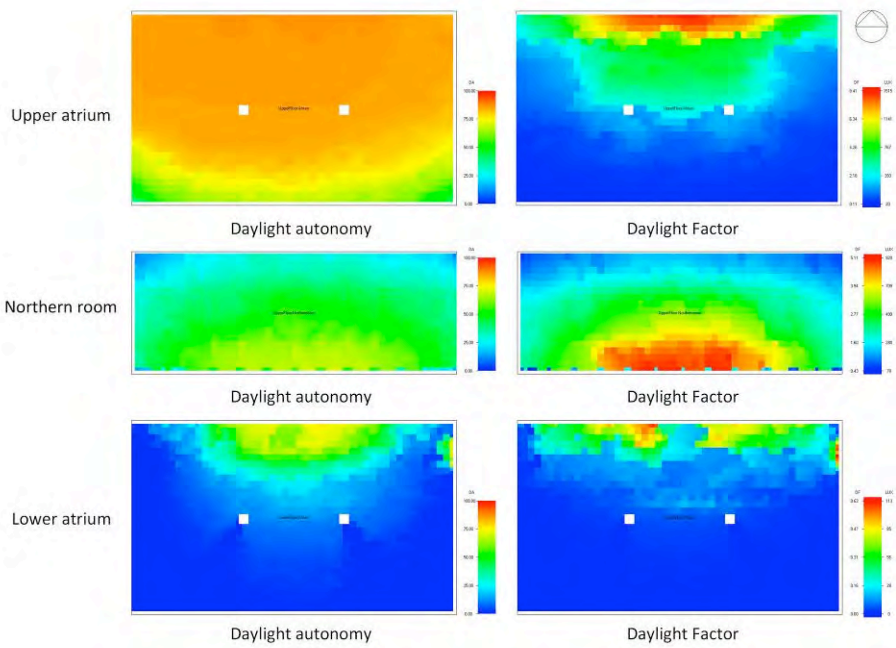
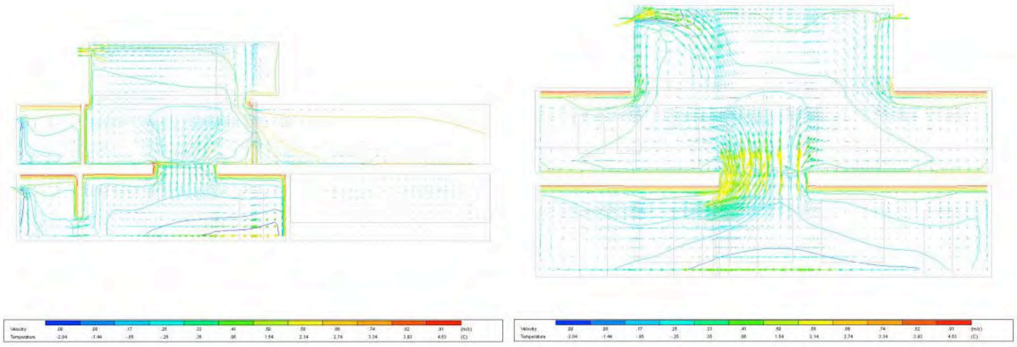
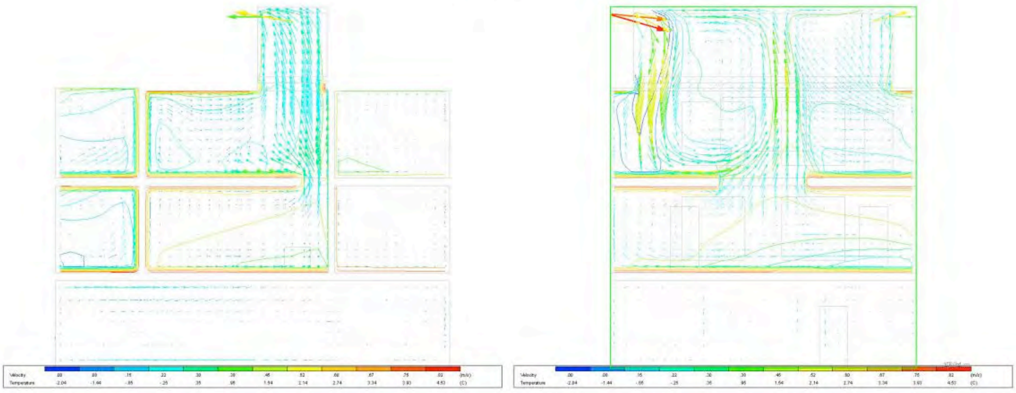


Figure4b. Natural lighting in Form2: small atrium

The status of airflow at 12:00PM on December 22nd are illustrated in Figure 5, in which obvious bottom-up airflow through the horizontal opening can be found in both Forms. and the southern and eastern opening of the skylight are the export for the airflow by buoyancy, and the velocity is between 0.25 to 0.4m/s and can be sensible by human body. Cross airflow is also found between the western and eastern openings of the skylight in the two forms.



Form1:large atrium



Form2:small atrium

Figure5. Airflow in the two forms

Conclusion and discussions

The archetype of Tibetan Monastery forms a system to control indoor environment. The second floor is the primary space in this building, for which the skylight and the first floor play the role of transition space.The result of airflow simulation indicates that the natural ventilation by stack effect can be obviously achieved through the system, while the cold outside airflow in from the entrance was warmed up in the first floor before entering the upper floor. The result also suggests that cross ventilation is unavailable in this archetype. In terms of natural lighting, the upper atriums in both forms have sufficient illuminance for most of the time. The northern room on the top floor can also benefit from direct natural lighting for a certain degree, but depends on the the depth of the skylight, namely the horizontal distance between the side window of the north room and the south opening of the skylight. Despite an enclosed space, the lower atriums also obtain certain amount of illuminance by lighting through the horizontal opening. Compared with courtyard or patio, the system finds a solution responding to local climate, which provides natural ventilation and lighting while reducing the amount of building envelope open to the outside space.

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Design to Thrive

To evaluate the environmental performance in Vernacular settlements of Kerala

Ameena Junaize[1], Sujata Karve[2] and Namrata Dhamankar[3]

[1] Department of Environmental Architecture, Dr. Bhanuben Nanavati College of Architecture for women, Pune, India, ameejunaize@gmail.com
[2] Head of Department of Environmental Architecture, Dr. Bhanuben Nanavati College of Architecture for women, Pune, India, sujatakarve@gmail.com
[3] Faculty at Department of Environmental Architecture, Dr. Bhanuben Nanavati College of Architecture for women, Pune, India, namrata.dhamankar@gmail.com

Abstract: Vernacular settlements evolved around the world with a sensitivity towards climate apart from their ethnicity and socio cultural dimensions. This paper will aim to study the varying environmental performance of three vernacular settlements in varying topographical regions in the warm humid climate zone of Kerala, India on the basis of thermal performance. The flexibility of vernacular settlements produces variety not compliant with generalization. The research thus studies whether the contextual difference in these settlements affect the thermal performance of their built environments in the same climate type of warm and humid. The proposed methodology examines the environmental parameters that have affected the building level. For a thorough understanding of the same on site validation and systematic quantitative analysis is carried out. The research methodology has evaluated the said terms on thermal comfort of occupants and socio-cultural precinct as well. The questionnaire survey recorded the thermal sensation of the occupants and a comparison between the typologies was done. The results of the study shows that the parameters of climate vary in spite of topographical variations and cultural difference in spatial planning. It thus identifies the lessons learned from vernacular settlements that could be applicable in contemporary new age community planning as well.

Keywords: Vernacular, Thermal comfort, Climate, Socio-cultural, settlements

Introduction

The vernacular settlement can be interpreted as a pragmatic response to how territorial interventions, on a community scale, are directly conditioned by its geographical features. The settlement is developed in specific models according to its particular climate, geomorphology, geology and available resources, which are materialized through formal solutions adapted to specific socio-cultural perspectives (Guillaud et al., 2014). Climate has a major effect on the performance of the building and its energy consumption. Reducing energy consumption, using natural resources and providing comfortable, healthier and sustainable living spaces are the aims of a climatically responsive sustainable building design (Holmes and Hacker, 2007). Vernacular built form based on building traditions are ecologically fit and may have a sound source of information. A need for place dependent sustainable architecture has to be formulated (Eyüce, 2007). The environmental design features that have been incorporated in the design of the vernacular buildings vary from their location in the plains to that in the mountainous areas in order to adapt to the local climatic conditions. Variations of local climate, depending on altitude and proximity to the sea, have created a variety of bioclimatic design solutions which are specifically adapted to vernacular rural dwellings of specific regions. A number of various functions of the dwelling which have had to meet different comfort requirements have led to the division of internal dwelling spaces into multiple thermal zones offering thermal diversity in the traditional house. (Philokyprou Maria et al., 2014)

This research aims to arrive at a more comprehensive overview of the thermal performance and comfort of Vernacular settlements in Kerala. For this three settlements of varying context and physiographical location were studied. The research studied whether the contextual difference in these settlements affect the thermal performance of their built environments in the same climate type of warm and humid. The objective of the study is to analyse the spatial characteristics of these settlement and evaluate the performance of the vernacular structures in terms of thermal performance of indoor areas. The paper also studied the socio cultural precinct of these settlements.

Description of study area

Kerala state lies on the south western coastal region of the country between latitude 80 17’ and 120 47’ N and longitude 740 52’ and 770 24’ E. It is spread over an area of 38863 sq. km or about 1.2% of geographical area of India. Physiographically, the state can be divided into coastal, midland and highland zones as seen in Figure 1. Rainfall varies from 1520mm to 4075mm and the temperature ranges from 19.80 °C to 36.70 °C.

From the physiographic division of Kerala as seen in Figure 1, a vernacular settlements from each region were chosen as study areas from the assessment of thermal comfort and sociocultural evolution. The settlements chosen for study are typology: 1 (coastal settlement-Calicut), Typology: 2 (Settlement on the plains- Palakkad), Typology: 3 (Highland settlement-Wayanad).

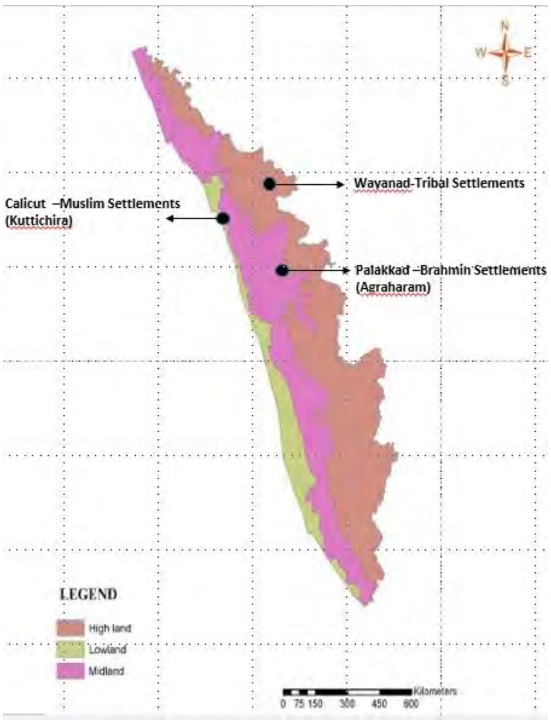


Figure 1. Physiographical Map of Kerala (Source: Department of environment and climate change, government of Kerala)

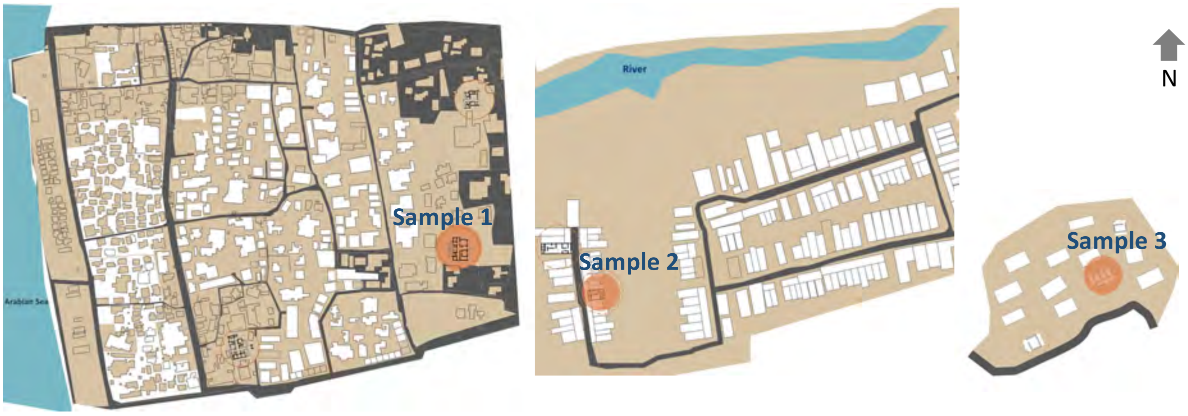


Figure 2. Habitat Sample location marked on Settlement plan, from clockwise typology 1,2,3 *(Source: Author)*

Table 1: Built features of the settlements

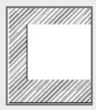
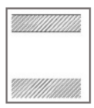
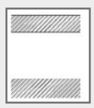
Typology	Habitat	Size	Material	Solar passive features	
1.Coatsal Settlement	Bungalows and individual houses	400-500 houses per settlement	Laterite walls, tiled roofs with timber.	Verandah 	Courtyard 
2.Midland Settlement	Row houses ,small and large	100-200 houses per settlement	Laterite and brick walls, tiled roofs with timber.		
3.Highland Settlement	Individual huts	10-15 houses per settlement	Mud-walls and bamboo reinforced walls ,thatched roof with bamboo rafters.		No courtyard

Figure 3. Samples of habitats chosen and sample spaces marked, study the Thermal performance Clockwise - Sample:1, Sample:2, Sample:3 from Typologies 1,2 and 3 (Source –Author)

Figure 4. Exterior View of the samples of habitats chosen to study the thermal performance (Source –Author)

Research Methodology

The research methodology is a case study based method. This study examines how the environmental parameters and topography influenced the interior thermal comfort in three vernacular settlements of Kerala. The proposed research methodology is based on a quantitative and qualitative assessment of the built fabric at the chosen samples. The qualitative investigation concerns with the study and documentation of the three samples for thermal performance. Field work was undertaken to evaluate the thermal performance of 3 typical samples of single storey habitats from the settlements chosen. For the said purpose, the research is carried out with two major aspects - Thermal performance and Socio cultural aspect.

To investigate the thermal performance, thermal comfort of occupants and their opinions which are theoretical and practical investigations will be carried out. Theoretical investigations comprises of literature on comfort models and predicting comfort temperature (ASHRAE etc.) , thermal comfort and its relationship to outdoor temperature etc. Practical investigations include the study of climatic Parameters (outdoor temperature, indoor air temperature, humidity, and air speed) at intervals using meters (5 in 1 meters) and compare the values with ASHRAE standards of indoor thermal comfort. The spaces considered for experimental investigation are the semi open space (Veranda), courtyard, living room and the bed room. These spaces were selected since all the activities happen around these areas from morning to evening and 90% of the household activities happen around these spaces also the spaces are active throughout the day. The data from various areas were taken at a height of 1m from the ground at morning and afternoon for a week, with the windows kept open for unobstructed air flow through the courtyard. The artificial means of ventilation like fans were kept off and un-operated till the experiment was over. A questionnaire survey based on ASHRAE scale of thermal comfort, preference and acceptance is carried out. According to ASHRAE Standard 55-2013, thermal comfort is defined as “the condition of mind that expresses satisfaction with the thermal environment”. Comfort may also be defined as the sensation of complete physical and mental well-being of a person within a built environment. The comfort conditions of the individuals depend on various physiological and environmental parameters. Study of thermal comfort standards suggests that most people are comfortable in the temperature range between 18°C and 30°C, with air-velocity 0–2 m/sec and relative humidity conditions between 30% and 70%, mentioned as ‘comfort zone’ on the psychometric charts. (Ashrae,2013).

The spatial organization and the impact of culture and tradition on spatial design and flexibility, are the major aspects to be considered for ensuring the quality of life. (Priya et al., 2012). Spatial configuration is a technical term that refers to the particular way in which a set of spaces are connected to one another as a network. Semi-structured interviews with residents, local experts (design professionals, local authorities, architects, builders, and locals) have been carried out.

Observations and findings

Comparative analysis

Field measurements were taken for selected samples from mid-January to February 2017.The comparison between outdoor and indoor temperatures and relative humidity from Figure 5 reveals that typology 1 maintains an average difference of 3- 4 °C temperature change, typology 2 maintains 2- 3 °C temperature change and typology 3 which is the high lands habitat maintains a temperature difference of 4-5 °C. This was due to the materials used for construction like mud wall, and thatched roof system.

From Figure 5 we can see that the morning temperatures are within the ASHRAE standard of indoor comfortable temperature of below 30°C for typology 2 and 3. Typology 1 has most of the spaces above 30°C.The relative humidity variation was found to be minimum in the typology 1 settlement even though the wind speed were higher in the range of 0 - 2.6m/s which is due to the presence of courtyards and large openings on all sides. Most of the spaces had wind speed more than the comfortable range of wind speed by ASHRAE standards. The relative humidity in typology 3 was observed to be in the range of below 30% that is lesser than the comfortable range by ASHRAE standards. Hence the use of mechanical ventilation was observed. The relative humidity at typology 3 was observed to have variation diurnal variations of 20-30% between mornings and afternoons, and in turn had wind speed within comfortable ranges of ASHRAE standards (below 2m/s) as shown in Figure 5C.

Thermal performance of different spaces between the settlements

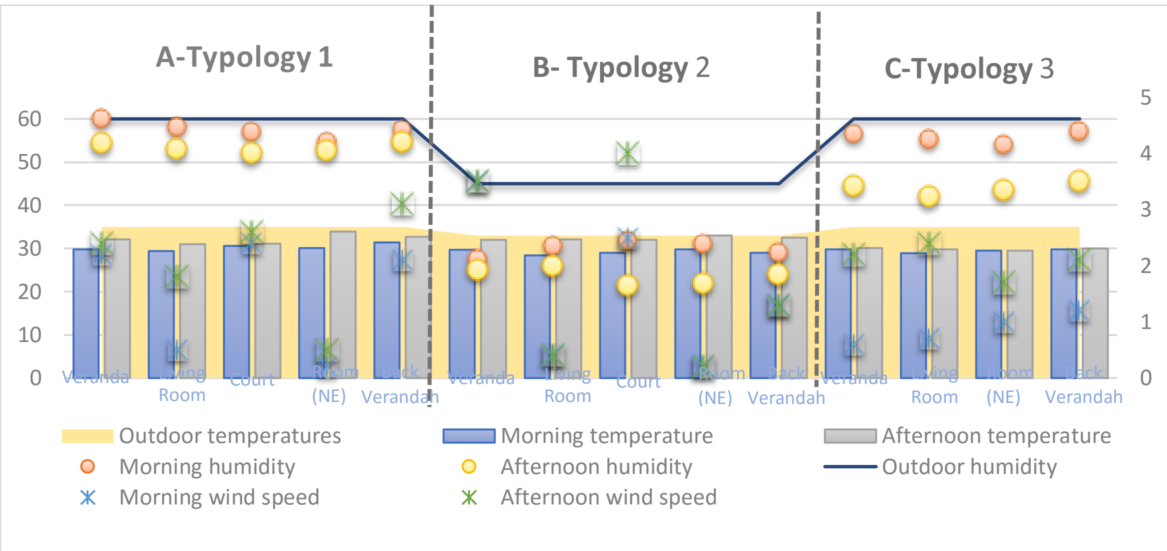


Figure 5. A, B, C, shows the weekly average Temperature humidity and wind speed and outdoor temperature, humidity recorded (*Source – Author*)

The weekly average of the maximum and minimum temperatures in Figure 6 of different spaces across the typologies like Verandah, living room and back verandah shows that the maximum and minimum temperatures are in the range of 29 to 32 °C typology 1. In typology 2 has the lowest temperatures indoor temperatures of 27-28 °C as compared to others. In typology Diurnal Variations in the range of 3-4 °C can be observed. The Diurnal variations between minimum and maximum temperatures of 1 °C is observed in typology 3. From this comparison it has been observed that the Typology 3 settlement complies with ASHRAE standard of maintaining temperature below 30 °C. Typology 2 shows lowest temperatures mainly due to the linear row house arrangement and higher air flow as most of the habitats were oriented linearly in the windward direction. The presence of courtyard helps in maintaining min and max temperatures due to the air flow.

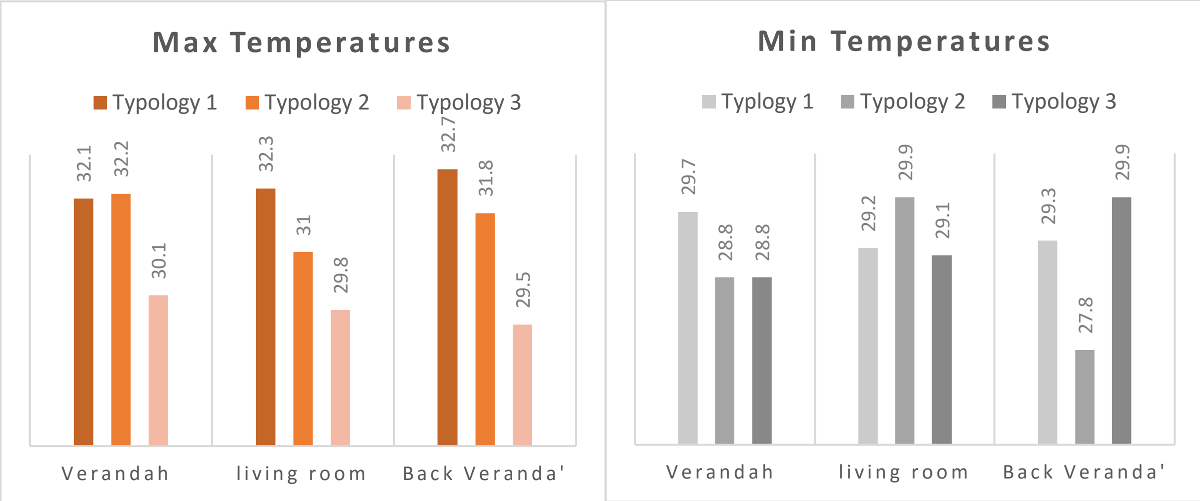


Figure 6. shows the thermal perception of human with respect to the thermal sensation, feeling of comfort, satisfactory level of comfort in the three places. (Source –Author)

Socio Cultural Analysis

Based on the interviews, one of the main considerations for different architectural types is the issue of privacy provision and public-private territories.

In typology 1 the main assessment is the privacy provision and public-private territories. Being a matrilineal society the spatial configuration gives importance to spaces used by women and that occupies majority of the plan. The spaces such as verandas were originated as buffer spaces for women between public interactions of the male members of the habitats. The spatial configuration of the courtyard lies in the women's quarters of the habitat and hence forms a major area for informal interactions amongst women.

In typology 2 social and cultural interactions were seen by the varying use of the veranda space. This settlement of row houses is a temple town and the veranda space was originated as shading area for devotes during processions there by forming a cultural impact of the space .The courtyard originated mainly for rainwater drainage between sloping roofs in the compact row house arrangement. The social status of a habitat can also be observed by the presence of granary which in the olden days were used to store agricultural produce.

In typology 3 spatial configuration division or public-private division has not been seen in these settlement.

Questionnaire Survey Analysis

Questionnaire survey based on ASHRAE scale of thermal comfort, preference was carried out on 75 persons who are inhabitants from each of the three settlements out of which 46 were female and 29 were male and the results were evaluated. It asked participants about the direct sensation of indoor thermal environment in terms of temperature, humidity, air movement and overall thermal comfort. There was no estimation calculation method applied in this case study.

More than 70% of the occupants in all the three settlements mentioned the temperature as not acceptable. The majority of the 30% occupants who said the temperature was tolerable was from the highland settlement typology 3.

The Figure 7 shows the direct sensation of thermal environment in terms of thermal sensation, feeling of comfort, humidity and air speed. Figure 7A shows that the 40% of typology 3 occupants felt slightly cool irrespective of the outdoor temperature and 30 % of typology 1 occupants felt slightly warm due to the higher air temperatures. Most of all 45-50% of occupants from all settlements felt the thermal sensation at the moment was neutral. The Figure 7B shows that the 50% of the occupants of typology 3 are comfortable and 50% occupants of typology 1 are comfortable warm.

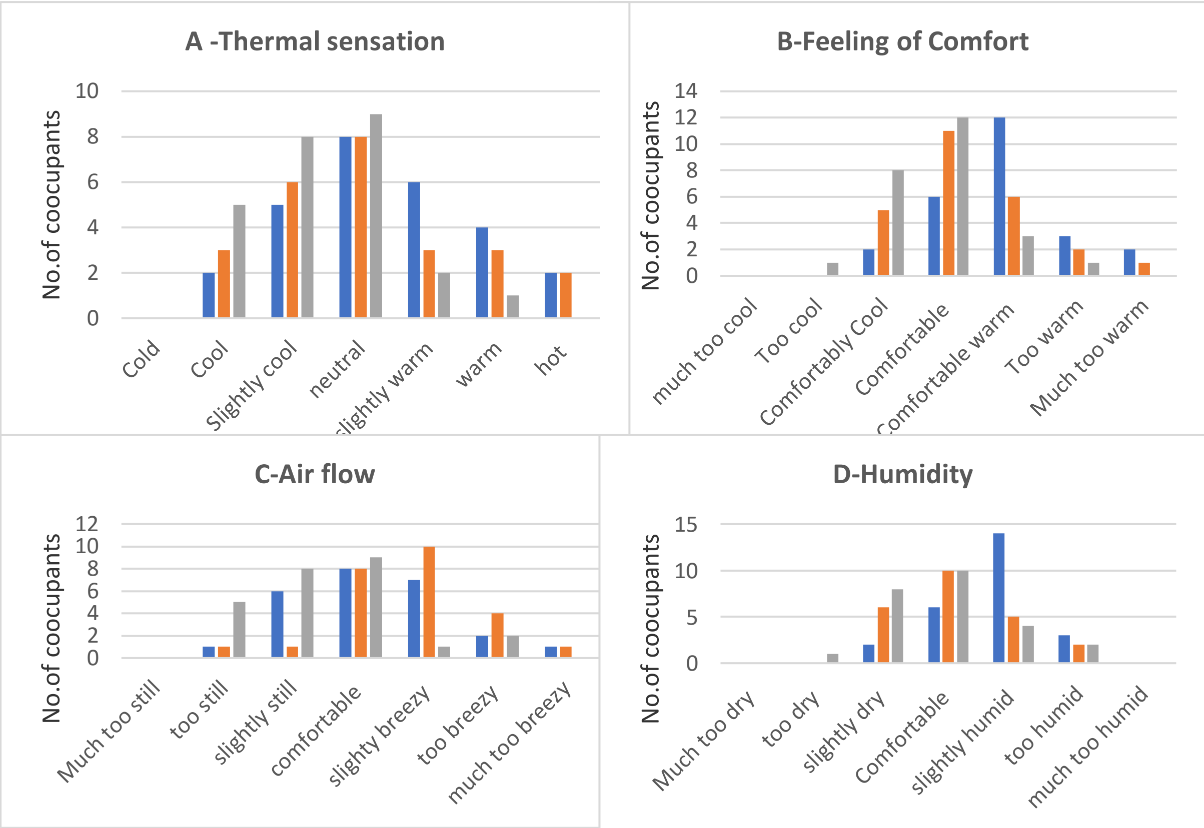


Figure 7. Shows the thermal perception of human with respect to the thermal sensation, feeling of comfort, satisfactory level of comfort in the three places. (*Source –Author*)

Discussions

It can be concluded from the quantitative analysis based on physical reading and qualitative analysis based on questionnaire surveys for thermal performance that the typology 3 settlements is more thermally comfortable to occupants. This can be mainly due to the use of materials like mud walls, thatched roof that helps in thermal insulation. The assumption for significant temperature difference between inside and outside temperatures of all three traditional habitats even during the highest outdoor temperatures is because of the evaporative cooling phenomena that takes place in mud and mud mortar based traditional houses in the case of typology 3 and the presence of passive cooling strategies of courtyards and verandas in the case of typology 1 and 2. The thermal environment in terms of humidity and air speed can be seen to have been modified in typology 1 and 2 due to the presence of courtyards .It can be also noticed that the diurnal variation between morning and afternoon indoor temperature is the highest in typology 3 .This can be attributed to the higher altitudes this settlement is located in.

Furthermore the study on social and physical aspects of the settlements reveal that the spaces originated for social interaction and public private buffers such verandas and courtyards act as major climate modifiers. Typology 1 and 2 habitats there is a difference of 2°C to 3°C in the spaces adjacent to the verandas ,i.e. the living room. An explanation to this result can be the buffer a wide veranda provides from the low angle sun. This point has also been confirmed by the onsite temperature measurements. Courtyards which were observed as spaces for social interactions may have thrived due to the maximized air velocities it provides in the spaces surrounding it.

Hence the typological variation in its spatial configurations according socio-cultural precinct does show a considerable difference in the indoor comfort parameters as separate entities. In typology 1 the large bungalows have a spatial configuration that allows maximum ventilation which is a criteria for the coastal habitats, typology 2 shows that the narrow row houses with only two openings have their orientation in such way for maximum ventilation punctured by courtyards, typology 3 has the optimum thermal performance by the use compact planning and traditional materials.

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Local Indigenous Practice of Traditional Community in Implementing Green Concept on Low Cost Housing Construction

Dewi Larasati ZR, Suhendri, Anjar Primasetra, Yuni Sri Wahyuni, Siswanti Zuraida, Sahid Mochtar

Abstract: As a developing country, and the 4th most populous country in the world, Indonesia still lacks of housing. Thus, mass rapid construction method is needed in housing construction in Indonesia. However, this massive housing development could lead to destructive effects on environment. It is important to make the housing development follows green concepts in the execution. Local indigenous of traditional community is acknowledged as one of the sustainable ways to build. The traditional method is known for its small environmental impact. This paper discusses the sustainable house construction method of Kampong Naga community, one of the remaining traditional villages in Indonesia. Field observation and interviews to the stakeholders of Kampong Naga were done during the research. The result shows that Kampong Naga has implemented some of green concepts in their traditional construction method, which has been inherited since hundreds of years ago. The villager is efficient in material use, also wise in site-planning, effective in building design, and even in the construction process. This paper focuses on local indigenous practice in building construction materials. Quantitative analysis was conducted on the use of sustainable materials by local communities with a life-cycle analysis approach to see the value of embodied energy and the environmental impact. Then a comparative study of embodied energy values and environmental impact between traditional houses and modern community homes was carried out. The result is expected to be an initial endorsement for the strategies of green concepts implementation in modern context.

Keywords: green building, local indigenous, low-cost housing, passive design, sustainable material

Introduction

Sustainable development has been introduced to Indonesia since three decades ago. However, the term is not implemented well in the country, and thus environmental destruction in Indonesia still at a high rate. Construction industry, particularly housing industry, is still the main contributor to energy consumption. It is well known that the most massive energy usage comes from air conditioning. Along with its energy consumption, construction industry also emits a huge amount of carbon dioxide (US EIA, 2012).

There are some efforts already done, either by Indonesian Government and the society, in promoting environmentally sound development. One community that is recognised for their practice in sustainable development is Kampong Naga. Kampong Naga is one of the traditional villages, located in Neglasari Village, Salawu District, Tasikmalaya Regency. Kampong Naga's people have implemented principles of green construction for years, as old as the village. The principles of green building implemented such as climate responsive design, utilisation of local materials, and passive solar architecture (Yeang, 2006).

This paper elaborates principles of green building concept in local indigenous practice of house construction in Kampong Naga. The green concept is considered since site planning to building design, as well as in the building construction. First discussion of the paper includes *genius loci* in site planning, materials selection, indoor air quality, daylighting, and construction process. Then, the paper focuses on the utilisation of sustainable materials by Kampong Naga's people. Lessons from the traditional values are beneficial for modern society in order to applying sustainable concepts in modern building.

Methodology

This research is conducted in three phases as follows:

1. In-depth study to construction techniques in the houses. This is done by exploratory case studies, to obtain good understanding of the general characteristics of house design and construction process in Kampong Naga.
2. Field observation and interview with the local community, especially the construction workers in the village. The observation focuses on traditional preservation techniques for bamboo, that usually used by people in Kampong Naga. The existing preservation techniques are then analysed quantitatively by using Lifecycle Cost Analysis. Analysis of the techniques specific for its environmental impact, particularly the effect of waste resulted from the bamboo preservation process.
3. Calculation of embodied energy materials of Kampong Naga's traditional houses. Embodied energy calculation for the traditional house is developed from Construction-Works Unit Cost Analysis (AHSP) published by Indonesian National Standard (SNI). Each work item on construction work has AHSP from the SNI. The AHSP consists of three components: material, labour, and equipment. By extracting material component from the AHSP, a detailed material usage of a building component can be obtained. Then, by referring to inventory data of material's embodied energy, the sum of material's embodied energy of Kampong Naga traditional house can be calculated.

Local Indigenous in Implementation of Green Concepts by Kampong Naga

Green concepts practiced by people of Kampong Naga include: 1) appropriate site development and water conservation in the village; 2) sustainable materials with low embodied energy; 3) low carbon emission in building operation with good daylighting and ventilation strategies; 4) local construction technique and labours, which is environmentally sound and prefabrication technique.

People of Kampong Naga are really strict to their site regulation. They have a clear mandatory site planning rules (Figure 1). Development of Kampong Naga is planned to three parts, such as:

1. Developed area, consists of housing area, service area, public buildings and public space, and place of worship;
2. Green area, consists of the village's including consumption forest used for daily needs, production forest used for economic activities, and sacred forest that is conserved;
3. Water conservation area, consists of fresh water conservation area for drinking and cooking, fishpond area, bamboo preservation pond, and waste water management area.

Figure 1. Site plan Traditional Community of Kampong Naga (source: Utami, 2014)

The developed area covers houses that are organised in form and location. The houses are rectangular in plan and built as stilt houses which are elevated 50-60 cm from the ground. They are commonly built as detached houses. There are also religious building, public space, and public building such as public toilet and granaries in the area.

Figure 2. Kampong Naga, Salawu, Tasikmalaya, West Java, Source: http://id.wikipedia.org/wiki/Kampong_Naga

Another part of the village, the forest, covers production forest, consumption forest, and sacred forest. The sacred forest has a holy significance for the people of Kampong Naga. It gives a spiritual and psychological effect to whose violate the prohibition of the forest. The forest is located at the near side of the village and surrounded by Ciwulan River as its boundary. The river helps to protect the forest from deforestation. Due to conservation of the forest, Kampong Naga always has natural fresh water storage in their village. It can fulfil the village's water needs for fresh water. Moreover, production area can be planted as paddy field, or farmland. It is located at the west and east side of the developed area. Another production tool is *sung lisung*, which is a building that used by the people for rice pounding.

Kampong Naga house is a stilt house that enables air movement below it. Massing of the houses is oriented in a north-south axis. Hence, the most radiated area in the east and west side of the building, only received solar radiation in a shorter time. Solar radiation is also blocked by wide roof overhang. This design strategy creates more pleasant indoor air quality. Further, the house layout drives cross-ventilation across the building. Besides, wall material that made of bamboo makes a kind of porous building that can deliver fresh air into the building (Figure 3).

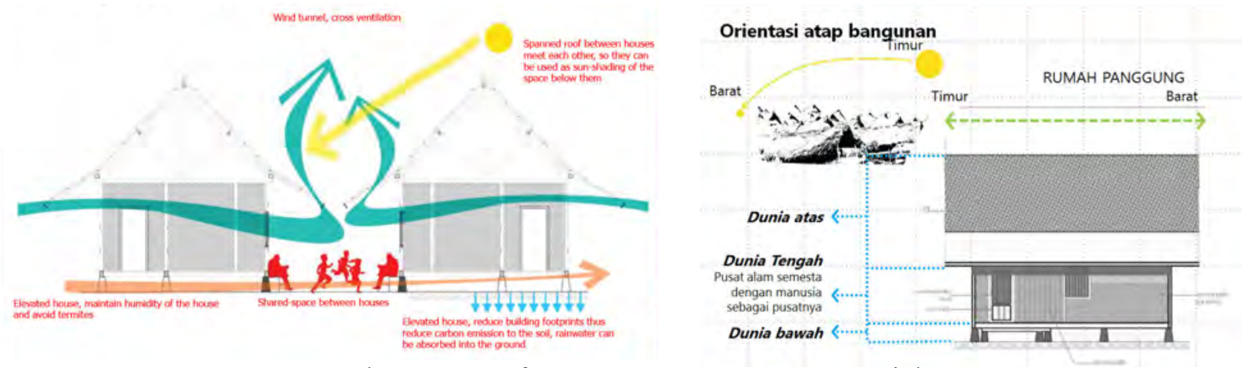

Figure 3. Implementation of Green Concept in Kampong Naga's house

The porous wall and openings also enable daylighting to occur in the house. Another design feature that brings daylight into the house is a chimney in the kitchen area. Beside its function as a channel for smoke from the kitchen to the outside, it also creates daylighting (Figure 4).

Figure 4. The use of day lighting in chimney, woven wall, and openings in Kampoong Naga Local House

Sustainable Material in Housing Construction

Houses in Kampong Naga cover 30-60m^2 area. They use naturally brow materials such as wood, bamboo, fibre or coir, and tepus leaves. Beside its availability in the village, the materials are also strong and durable. All of the houses are stilt house with Sundanese style (Utami et. al., 2014). The roof is design with traditional style called *julang ngapak*, with raised floor and pedestals and its column. The design has a philosophical meaning for the people, which combine environmental, economic, social, and cultural value.

The houses' roof material is coir or coconut fibre, and sometimes dried palm frond. The walls are made of bamboo, with wooden column, and stone foundation. Figure 3 displays bamboo material use in Kampong Naga's houses.

Kampong Naga exploits natural material such as bamboo and timber as building components. Based on the observation of some of the indigenous construction of the Kampong Naga is including:

1. The use of bamboo as a sustainable material. Bamboo is a material with a very short harvest period
2. A technique to increase the life span of bamboo, through the harvesting process, the process of preservation and storage
3. Use of the green building concepts in the arrangement of buildings and the construction of residential units
4. The application of the concept of local prefabricated, in improving the quality and the acceleration of the development process

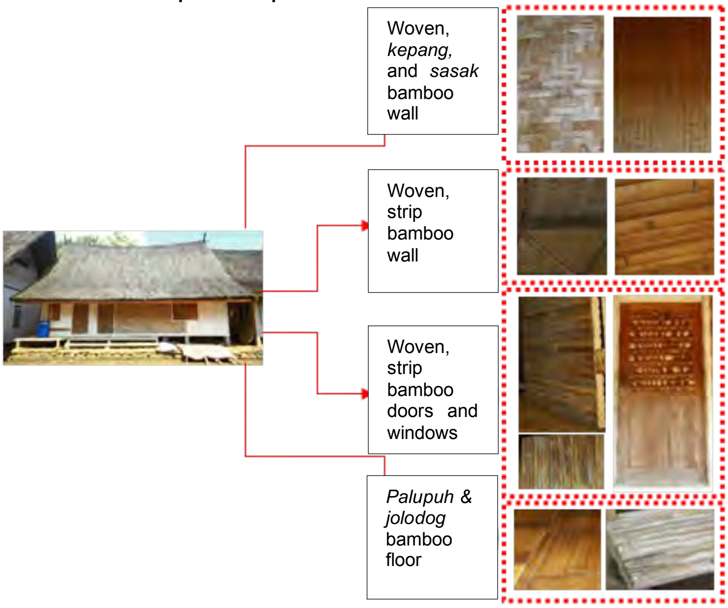

Figure 5. The use of bamboo material in some elements of Kampong Naga's house

In terms of Bamboo preservation method, the villagers also used traditional inherited methods such as a submersion in the preservation pool and coating technique with camphor (Zuraida, et al., 2015). Kampong Naga's bamboo preservation technique is considered as environmentally sound method. Table below comprises some bamboo preservation techniques that usually used in Kampong Naga.

Table 1. Characteristic of Bamboo preservation technique in Kampong Naga

Preservation strategy	Preservation technique
Harvesting	• Bamboo that is cut to be used in building construction is a minimum three years old Bamboo. • Bamboo cutting can be done anytime except at the full moon, Tuesday and Wednesday, because bamboo is not in good condition to harvest at those time. • It is better to cut bamboo at 11 am to 15 pm, or after midnight to the dawn, because Bamboo is not growing at those times.
Preservation	• Submersing the bamboo into a muddy pool for 1 to 3 months. This process is aimed at closing the pores of the bamboo in order to protect bamboo from insects. • Drying the bamboo below a shaded place for 3 to 7 days. • Covering the bamboo with calcium hydroxide solution to protect the bamboo from climate condition and close the pores. • Some bamboos are also painted.

Bamboo preservation technique by Kampong Naga's people is an environmental friendly process compared to modern preservation technique. This is implied by Table 2 below. The table shows comparison of environmental impact of different bamboo preservation techniques.

Table 2. Environmental impact of bamboo preservation techniques

Preservation techniques	Environmental Impact		
	Human Health	Eco Toxicity	Resource Depletion
I. Traditional			
Submersion in a muddy pool	0.00000	0.00000	0.00000
limestone covering	0.00003	0.00002	0.00002
Painting	0.00016	0.00012	0.00016
II. Modern			
Scalding: *borax-boric acid*	0.00003	0.00001	0.00002
Sarpeco 8 injection	0.00069	0.00031	0.00065
VSD; *Borax- Baric Acid*	0.00191	0.00070	0.00123
Submersion in salt solution	0.00601	0.00281	0.00576
Filling with lubricant and oil	0.00726	0.00419	0.02531
Submersion in camphor and detergent	0.05042	0.02308	0.09670

Embodied Energy (EE) of Material Usage in Housing Construction

Total energy consumed by construction materials from its production to post-construction stage can be divided to embodied energy and operational energy. The amount of energy used in the process is considerably huge. This huge amount of energy clearly affects the environment. The environmental effect can be measured by using the total energy that is used in the whole construction life cycle. One of the indicators is embodied energy (Treloar, 1997; Dixit, 2013).

Calculation of Kampung Naga's traditional house are conducted for three type of house area: Type 21 m^2. Type 36 m^2, Type 45 m^2. These types are the common low-cost housing scheme constructed in Indonesia. The embodied energy calculation results of the three house types can be compared to embodied energy of modern low-cost house types the process is summarised by Figure 6.

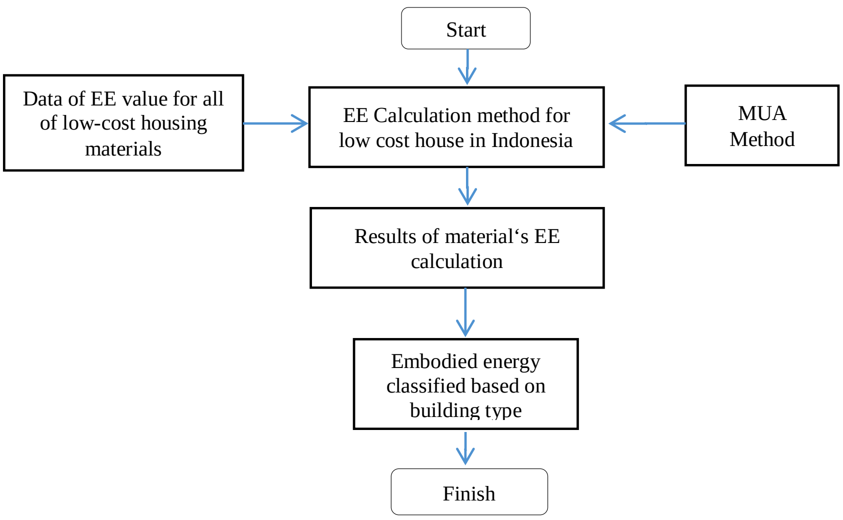

Figure 6. Calculation of material's embodied energy value used in this study (Yuni, et. al., 2015)

Table 3 below show the embodied energy calculation results. It compares embodied energy of Kampong Naga and modern low cost house.

Table 3. Comparison between EE values

No	Building Component	Embodied Energy (%) of Unit Types of Modern House			Embodied Energy (%) of Unit Types of Kampong Naga House		
		21 M^2	36 M^2	45 M^2	21 M^2	36 M^2	45 M^2
1	Site works	0,80	1,62	2,17	0,40	0,90	1,18
2	Foundation	10,81	14,43	21,25	7,18	32,91	26,38
3	Wall	52,79	55,20	65,72	7,97	14,62	20,43
4	Roof	58,06	69,73	89,30	3,66	3,66	4,39
5	Floor	0,59	0,65	0,86	0,00	0,21	0,25
6	Building Services	3,88	3,88	5,28	7,13	0,00	0,00
	TOTAL	126,93	145,51	184,59	26,34	52,30	52,63

Based on materials used in modern low cost house and Kampong Naga house, it can be seen that EE value of the Kampong Naga house is much lower than the modern house. This indicates that energy consumption in the whole life cycle of Kampong Naga house are much smaller. Thus, its environmental impact is lower.

Sustainable Construction Method

Houses in Kampong Naga are built using traditional prefabrication method. Kampong Naga prefabricated houses are made of bamboo building components prepared in the workshop with a particular standard which is done using a machine or manual, or a combination of both. Prefabricated bamboo products that made is often in the form of cubicle wall of bamboo, *Palupuh*, laminated bamboo, and bamboo sticks. Prefabrication method may accelerate the construction process and shorten the completion time. This can be seen in the observation of time spent by the workers on site, which is lower in the prefabrication building than the conventional one (McGraw- Hill Construction, 2011).

Prefabrication method used in Kampong Naga utilize local workforce in the process. Thus, the traditional techniques with high aesthetic value are preserved and inherited from generation to generation. Traditional technique tends to be more sustainable and have lower environmental impact. The techniques are potential to be used in modern way. Prefabrication level of people in Kampong Naga is surely high, with the componentization system and simple equipment.

Conclusion

Several types of implementation of green concepts have been applied by Kampong Naga's people in the building construction. Results from this study show that indeed the Kampong Naga's practice has a positive impact to environment. Some conclusions that can be written are:

1. Kampong Naga's indigenous practices in construction are in line with the concept of sustainable building, such as sustainable site planning and passive design for thermal and visual comfort.
2. The use of sustainable local materials with environmental friendly preservation technique have less impact to environment, as well as low embodied energy value;
3. Embodied energy of Kampong Naga's traditional house is lower than the conventional low-cost housing. The difference is mostly caused by material selection. Modern low-

cost housing development should consider this, since its conventional low-cost housing need to be more efficient in terms of embodied energy.
4. Beside the material selection, Kampong Naga also implements a sustainable prefabricated construction system. Prefabrication level of people in Kampong Naga is surely high, with the componentization system and simple equipment. It has been developing in the community since hundreds of years ago.

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The huichol traditional dwelling and the inhabitant adaptive response

Alicia Delgado López[1], Adolfo Gómez Amador[2], Eugenia María Azevedo Salomao[3] and Jorge Ojeda Sánchez[2]

[1] Autonomus University of Nayarit, Tepic, México, alicia@uan.edu.mx;
[2] Faculty of Architecture, University of Colima, Colima, México, amad@ucol.mx
[3] Faculty of Architecture, Universidad Michoacana de San Nicolás de Hidalgo, Morelia, México

Abstract: The huichol people are recognized as an ancestral culture that still preserves its customs and traditions. They are part of the 62 indigenous groups that inhabit the Mexican territory. Their houses reflect their worldview, consisting of several single space structures arranged concentrically in relation to a campfire. This is located at the center of a sacred courtyard. They are built from natural local materials as stone, adobe and thatch. Their construction techniques as part of accumulated knowledge have been passed on from generation to generation and reflect the close relationship with the natural environment. However, from the need for better climatic conditions they practice seasonal migration to another site of the western Sierra Madre, where they have other series of constructions that are recognized as an extension of their dwellings. The analysis of the climatic condition and the use of the psychometric card shows us that is an adaptive response. This study aims to show a further example of climate response that exposes a passive form of adaptation to the environment as a fundamental reason for human existence in the natural environment.

Keywords: Seasonal migration, migration pattern, huichol dwelling, adaptive response, vernacular architecture

Introduction

The huichol traditional architecture is a remarkable phenomenon because it is a correct architectural and environmental response to the local context and climatic conditions. Coupled with this, the historical context in which it develops, is the trigger for this form of adaptation to the environment. This is a response to the search of the desirable environmental comfort and the daily domestic and social activities.

This analysis is based on the theory of comfort from the perspective of the adaptive approach. From this point of view, thermal comfort is conceived as a mental state in which subjective and objective variables are involved that intervene in the energy balance between the human body and its surroundings through actions that the human being accomplishes to reach it, either, internally through physiological and psychological processes, as well as externally with adaptations to its surrounding environment (Gomez-Azpeitia et all, 2007).

The actions that can be performed to achieve this state of well-being can be grouped into four types: Modifying internal heat generation, modifying the heat loss rate of the human body, modifying the thermal environment, or moving to a different environment (Humphreys, 1981).

In this paper, we observed a huichol group that practice the seasonal migration from a place that is at 882m altitude to another site located at 351m altitude, in the bowels of the western Sierra Madre, in search of better conditions of habitability.

History

The huichol people habits the western Sierra Madre, between limits of Nayarit, Jalisco, Zacatecas and Durango states. The *wixaritaris* as they call themselves, is one of the Mexican original groups that preserves its culture and traditions now a days. The archaeological information has registered its origin since the prehispanic time (Weigand, 1998; Zepeda, 2003). At that time, many populations of huicholes ancestors habited valleys and low areas.

During the European people invasion, the huicholes were confined to the mountains area. Later, the invasion promoted by landowners and half-caste groups forced them to leave their accessible and productive lands. Fleeing from the harassment and mistreatment of the invaders, they managed to establish themselves in the mountains and canyons of the western Sierra Madre where today most of the huichol population habited (Torres, 2000; Neurath, 2002). The rugged topography and its variety of climates contributed to the way inhabitants adapted to these conditions to meet their most pressing needs (Braniff, 2004). Nowadays we can still watch the environment adaptive way for the resources exploitation.

Method

In order to carry out this research, field visits were made to obtain primary information through direct observation, the field trips in rural settlements were a few number of traditional Huichol buildings still exists. The localities which are considerate in the study are Los Encinos and Las Palomas. The field trips involved a detailed photographic record of the buildings stock, as well as an analysis of the typology and the morphology of the dwellings. Furthermore, the architectural survey of houses was made, as well as the registration of materials and construction techniques. All the above-mentioned observations are combined with a bibliographical study of the Huichol traditional architecture during the 19th and the 20th century, as an archaeological registry.

Focusing on the seasonal need for comfort, a comparative study of the winter and summer accommodation in terms of thermal performance was conducted. The environmental adequacy statistical information on climatic conditions from the Meteonorm 6.1.023 program was evaluated and analyzed in the Gomez-Azpeitia bioclimatic chart program. At the same time, the thermal behaviour of the Huichol dwellings was investigated using a computer simulation with the Design Builder 4.7.0.027 program. Measurements in existing houses in order to verify the simulation results were made.

Description of the dwelling

The huichol dwelling is formed by a series of mono-spatial constructions that settle around a campfire located in the center of a courtyard, as the architectural structures are ordered in the ceremonial places. At the same time, they are governed by the principle of the quincunx. The quincunx is a rhomboid cross which lines link with its main place of worship. In this way they set up their territory, their ceremonial centers and their domestic units denominated rancherías (Neurath, 2002; Torres 2000).

Each ranchería is seated in an isolated manner and dispersed around the main ranch belonging to the elder chief, secondary rancherías can belong to the sons or the wives. The domestic unit is made up of the buildings pertaining to the kitchen, parental shrine, barn, rooms, also integrate the orchard, farm, and the coamil. Those are buildings made with the local material such as stone, adobe, wood and thatch, which are characteristic of vernacular architecture. The typology of buildings is varied according to the construction systems and the combination of material used. Generally, the constructions are mono-spatial and the geometry is rectangular, the oldest buildings can be of circular plant or circular later walls (Lumholtz, 2006, Neurath, 2002; Torres, 2000).

In the example, we can observe that its rooms are built around a courtyard, around the centre of the courtyard we find a bonfire that represents the centre of the quincunx in relation to the place of worship that makes it up. (Figure 1).

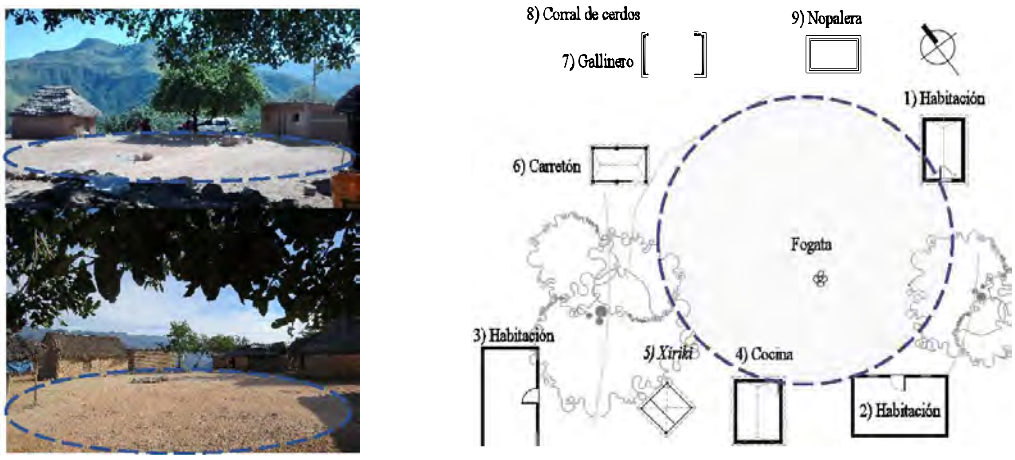

Figure 1. Los Encino´s dwelling.

The family shrine (xiriki) is a mono-spatial construction and it´s placed in the west, facing the central campfire with an east view. This building determines the position of the rest of the rooms. The kitchen is another construction that is located to the west of the courtyard and represents the main building of the ceremonial centre in analogy with the religious space.

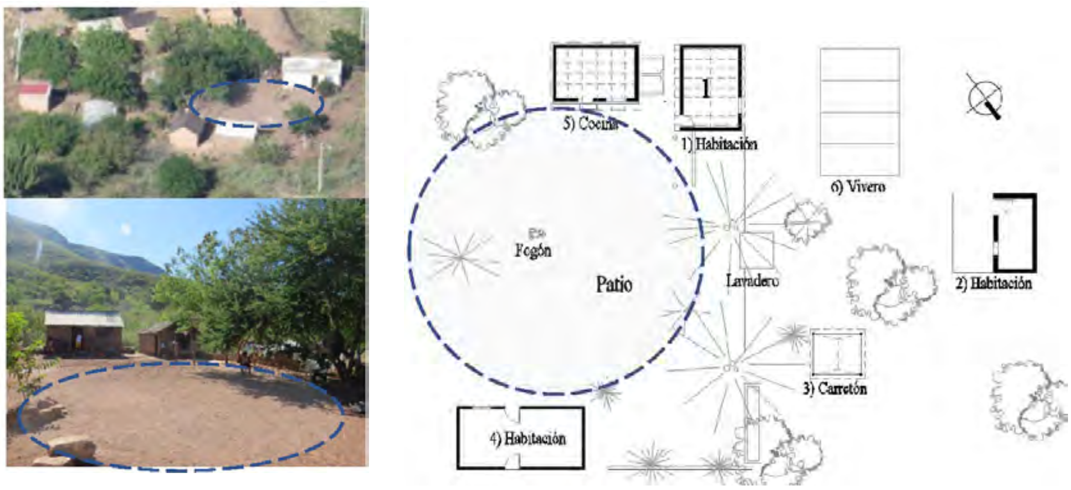

Figure 2. Las Paloma´s dwelling.

The barn (carretón) is also around the courtyard and is made of wood, otate (a kind of smaller bamboo), and thatch, rise from the ground almost a meter, its reed walls placed vertically or horizontally are permeable to the necessary ventilation for the conservation of the corn grain from its harvest. The rest of the buildings are placed around the yard in a scattered way; they are used to spend the night and store their belongings. The vast majority are mono-space rooms and are built with stone walls or adobe and thatch cover. The constructions in Las Palomas have the same characteristics with exception of the cover, it is made of asphalted cardboard instead of thatch and there is not a *xiriki* because this extension does not represent a ceremonial centre (Figure 2).

Los Encinos climate analysis

Los Encinos is a population located in the sierra of Nayarit at 881m altitude (INEGI, 2016) in the highlands we have a sub humid - semi warm climate (García, 1987). In general, the climate of the mountain is moderate during the summer and cold during the winter with 21°C annual average temperature, presenting 30°C as maximum temperature, and 12°C as minimum temperature. The annual precipitation is close to 800mm with a rainy season from June to October, with frequent rainfalls from December to February.

The psychrometric chart applied to these conditions is shown in figure 3 and indicates the requirements or strategies of air conditioning to be in comfort.

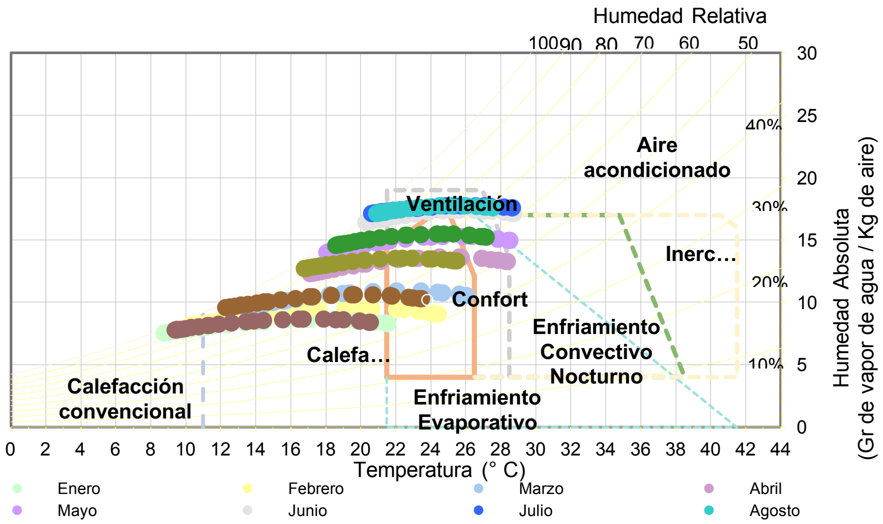

Figure 3. Los Encinos Psychrometric chart.

According to the psychrometric chart, in the period December to February, it is necessary to have an active heating system during the night and part of the early morning. While solar heating as a passive conditioning system is necessary most part of the year. In the months of June to August, the ventilation is important to maintain the comfort zone, only in a short time of the day air conditioning is required. In this part of the mountain a problem would be the conditions of low temperatures during the dawn in the months of December to February but the rest of the year the conditions of temperature that they present allow a state of comfort for its inhabitants.

The Design builder program was used for the simulation of rooms 1 and 2 with interior temperature conditions (figure 4). The characteristics of the buildings analyzed are shown in Table 1.

Table 2 shows the properties of the materials that were used in the computer simulation.

Room 1 is built with traditional materials. In the typical summer week this room has a similar thermal behaviour to the exterior in the early hours but a lower temperature than the exterior during the day. In winter, room 1 offers temperatures higher than the outside and oscillate between 15°C and 20°C whereas the outside temperatures are between 8°C and 15°C. That indicates the level of environmental adequacy of the building.

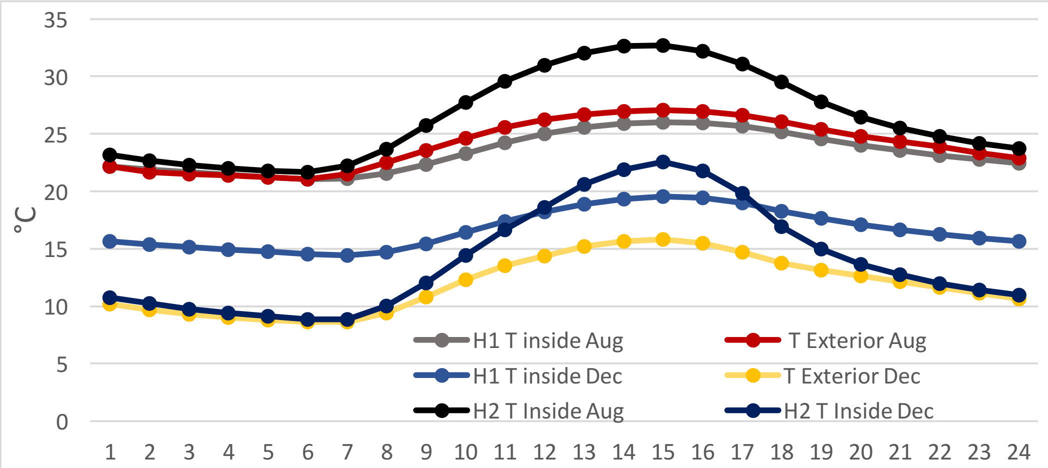

Figure 4. Los Encinos rooms 1 and 2, indoor and outdoor temperature data for a typical summer week from 10 to 16 August and a typical winter week from 22 to 28 December.

Table 1. Physical characteristics of buildings.

Los Encinos	***Dimensiones (m)***	***Materiales***		
	Ancho x largo x h:altura	**Muros**	**Cubierta**	**Piso**
Habitación 1	2.53 x 3.86 x 2.45h	Adobe	Zacate	Tierra
Habitación 2	3.70 x 5.80 x 2.30h	Adobe	Lámina de cartón asfaltado	Tierra
Las Palomas				
Habitación 1	5.43x3.88x3.00 h	Adobe	Lámina de cartón asfaltado	Tierra

Table 2. Thermo physical properties of the materials for the Design Builder program 4.7.0.027

Propiedades de los materiales	***Densida d kg/m3***	***Conductividad w/m°C***	***Calor específico KJ/m3°C***	***Emisividad***	
Adobe	400	0.30	900	0.40	González
Block de jal	1375	0.38	840	0.50	www.CRICYT.ED U.AR
Carrizo	800	0.15	1255	0.90	Elizondo-Mata et.all.,Manuel Martín Monroy
Mortero cemento-arena	1800	1.00	1000	0.90	ISO 10456 DB
Zacate	310	0.057	1300	0.60	BRE
Cartón asfaltado	1100	0.14	1140	0.90	Manual arq. Solar
Concreto	2400	1.80	1050	0.90	Rosales X.

In figure 4 we can observe the simulation of room 2, it is important to notice that it has a variation in the construction materials, its walls are of adobe and the cover is made of asphalted cardboard. During the day this building has a significant solar gain inside the room, temperatures raise from 4 to 7 degrees in the hours of greatest incidence. It is important to emphasize that during the day the inhabitants do the activities outside, in the shade of the trees. During the night the room is occupied to sleep and the interior temperature is similar to the outside with an increase of one degree of difference. This condition of higher temperatures than the exterior is unfavourable for the staying inside this construction, as opposed to the house with thatch cover that decreases the outside temperature during the day. It is interesting to observe that in cold periods, the traditional building offers higher temperature than the exterior, the effect of the heavy weight construction on the internal thermal environment is significant in the annual behaviour. The adobe walls contribute to better conditions because of their high thermal mass.

The migration to the place they call “rancho de secas” at the lower part of the mountain, on the side of the Chapalagana River occurs in October, once the rainy season ends and before the winter season starts. In this time the night temperatures start to decrease and an active heating system is necessary.

Las Paloma’s climate analysis

Las Palomas is located at 351m altitude, in the Chapalagana river canyon, in this place there is a sub-humid warm climate (García, 1987), with an annual average temperature of 25°C, with an average temperature range from 19°C to 36°C; the annual rainfall is about 700mm with a rainy period between June and October with frequent rainfalls in December and January; it has a long and hot period from May to September, with an about of 31°C average temperature (INEGI, 2016).

The psychrometric chart of the site shows that to reach the comfort zone ventilation and solar heating, passive acclimatization strategies are required. In October to April period, passive climatization strategies such as ventilation at day, and solar heating at nights. In April convective night cooling is recommended for a short time, all those are easy actions to obtain (Figure 5). In the period from May to September, the temperature conditions demand the implementation of air conditioning to achieve comfortable conditions in the place especially in the months of June, July, and August. This period occurs also when the seasonal migration to Los Encinos, in the up part of the mountain, takes place.

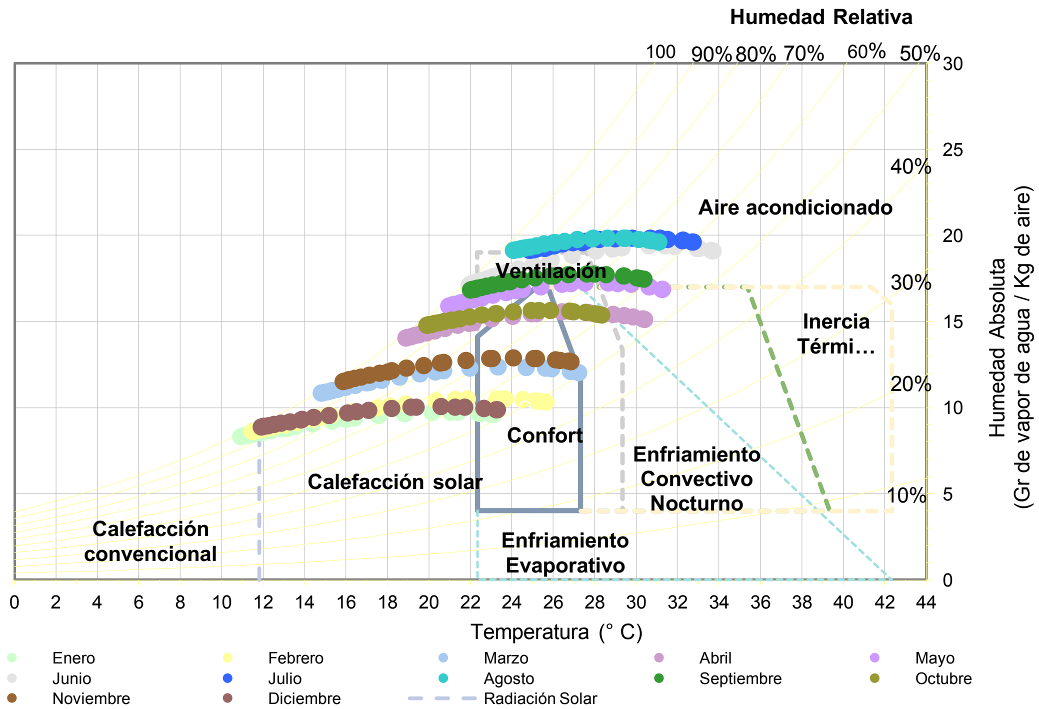

Figure 5. Las Paloma´s psychrometric chart.

In this place the interior temperatures simulation was made for room 1, the table 1 shows the room 1 construction characteristics used in the analysis of the thermal performance. Table 2 shows the thermo physical properties of the materials used for the simulation.

Figure 6 shows the thermal performance of the interior of room 1 in Las Palomas locality. In the simulation of a typical summer week, the temperature inside the room rises above 30°C after one o´clock. When the maximum temperature occurs outside, it does not exceed 30°C. As we can see in the psychrometric chart, these temperatures leave the well-being zone and an active air condition strategy is necessary.

In the months of October to May, when people are in that house, the temperature inside the building is maintained between 20°C and 26°C, it can be pleasant for their occupants and just passive strategies are required such as solar heating.

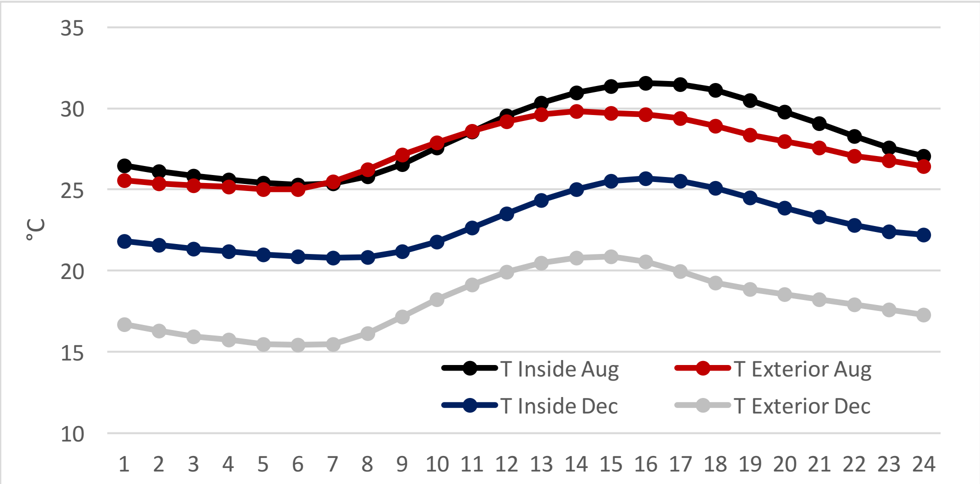

Figure 6. Las Paloma´s room 1 simulated temperature data for a typical summer week from 10 to 16 August and a typical winter week from 22 to 28 December.

Throughout the year the interior temperatures are higher than the outside temperatures, due to the materials with which the room is built. It is also observed that the interior temperature oscillates between 20°C and 25°C during the period of stay, this is a positive behaviour to stay at night, because the exterior temperature in this period is from 15°C to 20°C. The migration to the "Rancho de Aguas" as they call it to the high part of the mountain occurs in May when the maximum temperatures surpasses the line of 30°C and almost reaches 35°C in the month of June.

Winter exterior conditions at the Rancho de secas are more favourable when it is about 15°C to 21°C. Summer exterior conditions at the rancho de aguas are more favorable to stay, when it is about 20°C to 27°C. In the periods with conditions that require an active strategy, according to the psychrometric chart, the migration occurs.

Conclusions

By thermal performance analysed of the huichol dwelling in relation to the occupants´ way of living, we can conclude that by the necessity of better environmental conditions, the huichol dwelling occupants with the available resources, basic knowledge, and accumulated experiences, built their dwellings to stay in comfort throughout the year. What primarily improved their comfort conditions was the division of their house in two distinctive seasonal buildings divided by 550 m of altitude.

The occupants´ priority is to enjoy outside living spaces, where they could practice their communal outdoors activities with a comfortable environment. Therefore, the imigrating pattern is a direct response to this need. The forms of construction executed with simple mono-spatial isolated plants, scattered on the ground, with a single access span give us an account of the open-air life that they develop. The generous space at the center of the buildings indicates that there is an activity that accommodates many people, and it is directly related with their worldview. This also shows the relationship of the individual with his environment and the dominance of the rugged topography for the satisfaction of his needs.

Contrary to the data obtained in this analysis, traditional architecture is increasingly losing ground to the industrialized materials. Despite the fact that the constructions with sheets of asphalted cardboard offer worse conditions of habitability, they are preferred because its handling and placement is simpler than the former, as well as they represent a superior status than the one of the houses of adobe and thatch.

Through the research of traditional architecture, we can claim the concept of adobe and thatch housing and learn from its architectural design and living patterns of seasonal migration to reintroduce it in the current architecture and reduce global energy consumption in the domestic sector.

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Vernacular Architecture and Lessons of Sustainability: A case study of the old city of Salt, Jordan

Rana Matarneh and Ihsan Fethi

Amman Ahliya University, Amman, Jordan

Abstract: Much of the vernacular architecture in Jordan and elsewhere in the Middle East has suffered considerable loss and replacement by modern development. Only a few examples of authentic vernacular villages and old towns remain today. Traditional architectural design principles such as passive cooling and ingenious sustainable solutions were discarded in favor of wasteful modern technologies. The aim of this study is to explore the sustainable characteristics of vernacular architecture in Jordan through examining its physical relationship with climate and site and its capability to provide appropriate functional and social solutions. It focuses on the sustainable environmental design aspects of vernacular architecture in the Old Town of Salt, in Jordan. Thus, a detailed survey and analysis of some selected traditional houses was conducted with respect to typology, morphology, functions, and environmental features, building materials, construction methods and cultural features. It included a comparative analysis of different typologies in respect to orientation, insulation, shading, natural ventilation, and thermal comfort within the buildings. It is hoped that some valuable lessons could be identified from such a study which would help support not only conserving such vernacular buildings but also help formulate new building design codes for modern built environment.

Keywords: Vernacular architecture, sustainability, Old Town of Salt

Introduction

Cities are large complex human settlements that are persistently subject to technological, economic, cultural transformations throughout history but not without cost to the environment. The construction industry and its activity are held partly responsible for the substantial amount of global climate change and waste emission. Buildings account for 40 % of global energy consumption, 40 % of waste products, 12 % of potable water and 38 % of all global gases emissions. Consequently, energy crisis, climate change, and environmental pollution have positioned sustainability high on the global agenda. However, the industry has played an imperative role in promoting socio-economic growth and enhancing the quality of life. Sustainable development is now nearly globally regarded as part of the environmental movement forcing the construction industry to implement the principles of sustainability and support Agenda 21 - a global agenda for the transition to sustainability in the 21st Century. The urge of satisfying occupant's best wishes of controlling indoor environment resulted continuously in designing and implementing various mechanical climatic control systems to the extent of which buildings became separated from the external environment. As occupants progressively voice their demands for better life quality via local Agenda 21 initiatives, many architects, engineers and building researchers have been encouraged worldwide to study vernacular and traditional buildings to learn their effective optimization of energy consumption and whether such lessons could also be applied in contemporary construction (Wheeler et al, 2009). Vernacular architecture, although still regarded by some as being primitive or obsolete, has always been among the foremost and prominent references in sustainability studies and field research. Regardless of how it was designed or built there are valuable lessons that should not be ignored but treasured as valuable and proven experiences in smart passive environmental solutions. This is why vernacular architecture with its broad green design approach and strong connection to collective memory and regional identity still inspires many architects all over the world. There are many outstanding and highly successful examples of contemporary architecture that is essentially based on lessons derived from vernacular buildings. This study will show how vernacular houses of Salt Town can provide real and valuable applications to today's building industry. This research attempts to answer the following key questions:

- What are the sustainable characteristics of vernacular architecture in the Old Town of Salt, Jordan?
- What are the sustainable environmental design principles of vernacular architecture in the Old Town of Salt, in Jordan?

Sustainable Development and Green Architecture

Global warming and the need to significantly reduce the present high-level of emissions of greenhouse gasses require the utilization of new strategies for indoor climatic control. The prevailing building technology and modern materials, in many parts of the world, are still much biased on high energy consumption to provide thermal comfort indoors. On the other hand, vernacular architecture, at any place, has evolved through a long time of trial-and-error experimentation to achieve more efficient and indigenous solutions. Sustainable development has been defined in many ways. Johnson and Oliver defined sustainability as the utilization of technology in a moral and social responsible manner so that created buildings and cities respect culture, environment and culture of people. Another interesting definition for sustainable development that has been widely used today is the one developed by the World Commission on Environment and Development, (1987) contends that "sustainable development ... meets the needs of the present without compromising the ability of future generations to meet their own needs". Sustainable development can be achieved by optimizing the corporate collaboration in terms of moving forward towards producing ecological green products and implementing the most effective and efficient practices that maximize the use of local resources. Alternatively, "Green Architecture" is considered as the cornerstone of sustainable development that utilizes renewable energy, local resources and site location of a building with consideration of its impact on the environment. As such, green buildings provide a set of added benefits in terms of the efficient use of resources and significant saving in water and energy consumption which will contribute to a responsible environmental sustainability (Looman, 2007). Today, Jordan, as a developing country, faces serious challenges in terms of the limited and costly use of imported energy and scarcity of natural resources. Accordingly, developing sustainability practices through understanding the sustainable environmental design principles of vernacular architecture, could show far-reaching results in tackling these challenges.

Research Methodology

The research methodology examines Jordanian vernacular architecture by using an empirical approach that combines qualitative as well as quantitative analyses. Thus, it focuses on the importance of using passive design strategies and elements for sustainable development such as the importance of using local materials and local construction techniques and methods. Salt Old Town with its unique vernacular architecture was chosen as a case-study to test the degree of the sustainability of its old traditional houses. Case studies allow exploration of theories and provide opportunities understanding and in examining them at the ground.

Description of the study area

Salt was an agricultural town and administrative center in west-central Jordan in the late 19th century (As-Salt Greater Muncipality, 2016). It is on the old main highway leading from Amman to Jerusalem (Figure 1) Situated in the Balqa highland, and rises some 820 meters above sea level. It is built on a mountainous area, close to the Jordan Valley (Figure 2 & 3). Old Salt developed around the spring in the Akrad valley and on mountains tightly clustered in groups of houses and buildings built in local yellow limestone (Figure 4). Salt is one of the most consolidated and oldest urban settlements in Jordan that still maintains a significant part of its original character until this day (al- Hassan, 1995).

Figure 1. Salt map

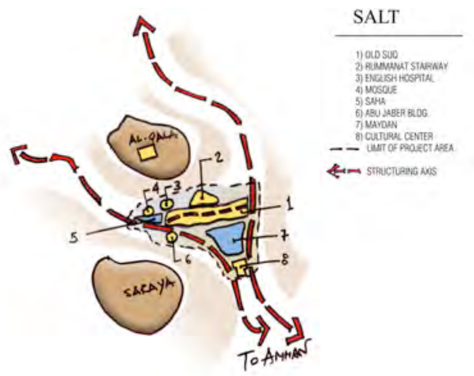


Figure 2. Urban structure of Salt

The oldest part of the existing fabric of the Old Town goes back to around 1850 when the Town began to attract migrants from the surrounding region and witnessed a prosperous period. Vernacular architecture of Salt Old Town is described as a blend of art and tradition. Houses are clustered in a unique spread across the three mountains ornamented with ochre-colored masonry that characterizes this particular town (Dawood, 1994, Khirfan, 2016).

	
Figure 3. Urban form of Old City As-Salt	Figure 4. Panoramic view of salt

Sustainable characteristics of vernacular architecture in the Old Town of Salt

Sustainable Site Planning

A major feature in the construction of the overall form of Salt is the sloped mountainous structure of its site. Thus, its fabric was shaped according to the topographic characteristics and spatial organization between different activities and zones within the old city were formulated in consideration of the climatic issues such as: the sun, prevailing wind and view of the site. Thus, geographical and climatic features of Salt had played a crucial role in determining the old town pattern, morphology and structure. The structure of the town was planned with narrow and windy streets that harmonized with the mountainous feature of the town as well as with the climate so as to offer residents shade protection from direct sunlight (Figure 5). While main streets went along the steep inclination in winding zigzag fashion, public steps were steeply inclined and took straight lines to reach the upper levels.

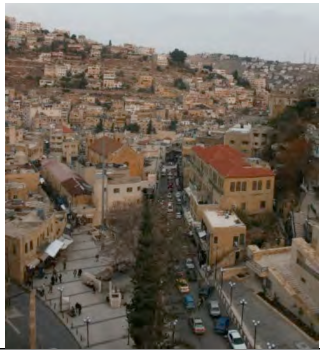


Figure 5. Winding zigzag fashioned streets in the historic core of salt

Having to settle on such a mountainous area meant a strong physical impact on its urban pattern which resulted in the utilization of terraced housing design as the basic building model. Settlements were influenced by topography so that buildings located on the slopes are connected with each other by steps which are accessible from stepped passages so that none hampered or closed off the view of another. Steps usually functioned as a public socio-cultural space where people met and communicated, and at the same time, they created the richness and variety in human circulation patterns in Old Salt (Figure 6). It may be concluded that local builders were aware of the natural potential of the site and, consequently, used it to achieve maximum benefits.

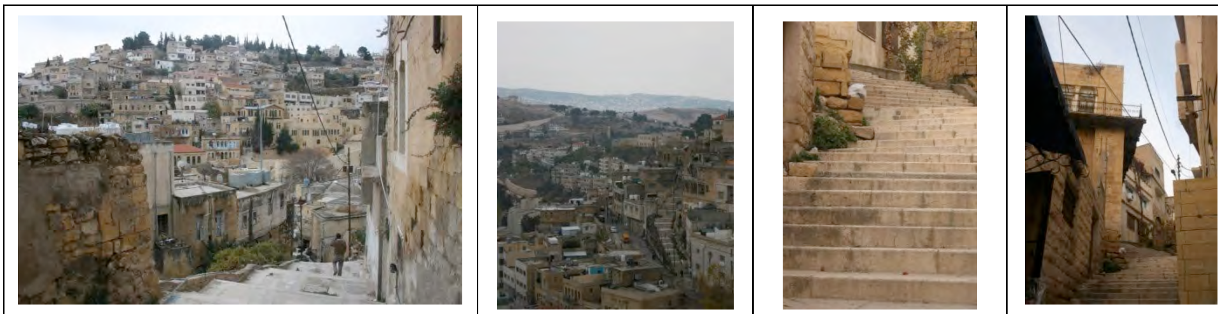
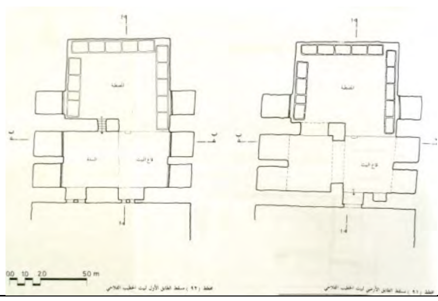


Figure 6. Urban stairs

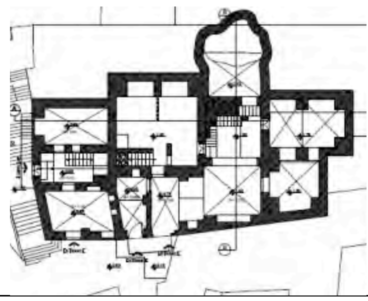
Building Typologies

Building Layout

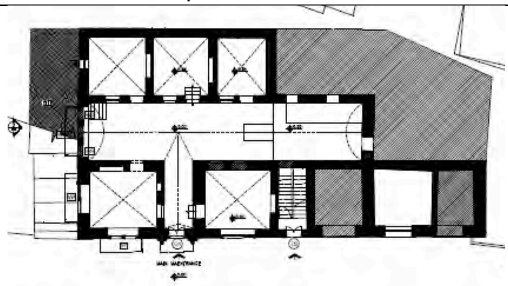
The building layout is a determining factor that enhances energy efficiency and imposes a degree of control over the climate conditions. Usually, the typical shape design varies as per to the cultural, historical, and urban planning traditions. Salt vernacular houses may be categorized into four main plan types: Basic peasant, courtyard, 3-bays houses, and detached villas (Figure 7).



a. peasant houses



b. Courtyard houses



c. typical 3-bay system houses

d. detached villa type

Figure 7. Salt's vernacular houses' typologies

A detailed typological analysis of Salt's houses is beyond the scope of this paper but some concise description is necessary. The evolution of vernacular houses in Salt Town is seen as a development model from the basic so-called spontaneous one floor "Peasant" house to the more elaborate other three, multi-story, urban types ending with the detached villa-type (Figure 7-a, 8-d). Houses seemingly formed irregularly due to the extension of rooms usable spaces inside the buildings or the construction of new neighboring buildings in the surrounding landscape. Generally, their contour followed irregular outlines of property boundaries to maximize the farmstead. However, the internal courtyard is found usually in more regular and large geometric land plots.

In the urban context, or where buildings are extensively connected, the courtyard may not appear as single but rather as several shapes where each was used to meet diverse functional and spatial needs. Significantly, the courtyard served not only as circulation zone, but also as one of the most important environmental parts of the passive cooling systems as outdoor and as living and working space. It is believed that the size of the courtyard is important to achieve an optimal level of both cooling and heating efficiency that is vital in hot and cold climates. The standard courtyards that are used in Salt's vernacular houses are relatively large, and with proportion that enhanced energy savings by offering adequate shading and maximize the gains during winter. Furthermore, they operated as a microclimate that harmonized the interior compared to the external environment. The northern cold courtyard and the southern warm courtyard were designed deliberately in order to provide adequate thermal comfort in the buildings by means of evaporative cooling and cross ventilation (Figure 7-b). The cold courtyard considered to be shaded in most of the daytime so that the flow of cool air into the building during the hot weather.

The central-hall, three-bay plan type (Figure 7-c), became the favored model for the prosperous middle class because it reflected the prevailing fashion in Greater Syria which then included Palestine and Lebanon. This plan type was an enclosed model that depended on a central hall for circulation on both two floors. The tripartite division of internal spaces was reflected on external facades and even on window shapes (Figure 8-a).

Orientation

Building orientation in Salt vernacular buildings was a successful method to enhance the effectiveness of the passive climate control. It has been noticed that, wherever possible, buildings were oriented towards the south and extended along the east-west direction with the intention of utilizing the passive heating which is supplied by the solar radiation. The overall area of openings on the north façade was the largest portion of the total area on exterior walls in order to reduce heating energy demand in the building. Orientation has been considered by traditional builders in most vernacular houses in Salt Old Town.

Openings

Salt's vernacular architecture, which developed over many decades, maintained an optimal interaction with climatic conditions especially the hot- arid summer. This essential fact, together with topography, governed the shape design of its buildings. Thus, the location of openings, size, height, and shape (i.e., straight lintels or tall arched with clear story windows) were used to provide natural daylight and good ventilation. In all Salt's vernacular houses, it is evident that careful consideration was given to the placement of openings on external walls as well internal courtyards in order to regulate wind and entice breeze (Figure 8-a).

		
		
a. Multiple tall-arched with	b. Cross-vaulted courtyard	c. Domed- roofs with thermal

Figure 8. Salt's vernacular houses' openings & roofs

Building materials, Resources and construction methods

The efficient use of materials is another track in achieving energy-efficient designs that interactively control climatic conditions. Traditional builders used local natural materials such as stone, brick, and wood that were tentatively renewable and which were generally rich in embedded energy and had the least degree of toxicity. They utilized materials of high thermal capacity for walls and roofs to regulate the temperature internally. These materials were known for their efficiency, in which they required less processing and were less damaging to the environment.

Thermal mass is a terminology used to identify materials that have the ability to absorb and store considerable quantities of heat to be embedded in masonry walls, roofs and floors. Salt Old Towns' walls were built typically using similar construction method. Buildings in Salt were constructed of abundant natural materials available in its geographical topography until the mid of the 20th century. Additionally, mud, straw, adobe and stone walls were being used as thermal masses because they were characterized by their capacity to limit the penetration of heat during the daytime and exchanging this heat externally during the night. Moreover, these materials were capable of creating 'flywheel' effect. Thus local materials were applicable choices for a good solution to control solar radiation to achieve sustainable energy performance. Vernacular houses of Salt employed domes and vaults widely to cover their rooftops. Vaulting, both barrel and cross-vault, was an ancient structural system that was used as an alternative to timber which was a rare material in the area. Barrel vaulting worked well for long narrow spaces while cross vaults and domes suited square spaces well (See Figure 8-c). Vaults were used as an essential element since it used locally available natural stones, and offered the possibility for natural sky-lighting, passive cooling**,** and ventilation. The warm air-flow under the vaulted roof through the openings placed on the far sides of the vault. Apparently, the key factor in determining the design of the vaults was the direction of the prevailing wind which was north-westerly in direction.

Conclusion

Salt Old Town is an extraordinary model representing an optimum harmonization of ecological, economic and physical factors which enhanced the integration of **s**ite, building development and cultural landscape. Hence, a proper site management enabled builders to capture the land's potential views, energy access including solar system, cooling from prevailing wind by lessening disturbance to the site and surrounding areas. Obviously, they have ideally applied, or knew how to apply, environmental and cultural resources that boosted energy efficiency. However, climatic conditions of Salt played a crucial role in transforming the vernacular architecture technologically. Moreover, the overall vernacular construction process of the old Town of Salt shows a clear manifestation on genuine architectural solutions that reflected the human desire for a truly functional, economic and comfortable environment.

This study proved that sustainability in old Salt houses was a necessity and a 'way of life'; not just a concept or an incidental social belief. Learning from traditional builders, we should go beyond the geometrical and physical calculations, formalistic notions and symbols, to a more focused attitude toward the harmonious relationship between man and nature. Perhaps, what matters really in vernacular architecture is not the traditional building themselves or their styles but, rather, the consistent respect for the natural environment and the basic principles of sustainability. Salt's vernacular architecture has a proven track record in terms of using sustainable materials, designs and construction methods that have been incorporated to cope with the local environment.

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Design to Thrive

Investigating the effect of the Takhtabush on the courtyard thermal performance

Mady Mohamed

Department of Architecture, Effat University, Jeddah, KSA (On Leave, Zagazig University)
momohamed@effatuniversity.edu.sa

Abstract: The Takhtabush "A covered outdoor sitting area at ground level" was introduced in the Mamluk period in the 12th century to the traditional courtyard in Egypt (El-Shorbagy 2010). It is located between the shaded courtyard and the backyard, opening completely onto the courtyard and through a Mashrabia onto the backyard which ensures a steady flow of air by convection (Fathy 1986). Several studies investigated the thermal performance of the courtyard and few of them highlighted on the importance of the Takhtabush. No one investigated how far the Takhtabush can affect the thermal performance of the courtyard. The author of this paper doubts the efficiency of the courtyard without the Takhtabush in hot arid zone where the air velocity during the summer is very low most of the time. The current research conducts a comparative study between two scenarios of the courtyard (with and without the Takhtabush) through technical investigation. The investigation is done using monitoring techniques with observation and field measurements. Data is analysed using statistical analysis software. The results showed quantitatively and qualitatively the importance of employing the Takhtabush to enhance the thermal performance of the courtyard.

Keywords: Courtyard, Thermal Performance, Takhtabush

Introduction

Houses represent the background or framework for human existence (El-Shorbagy 2010). Through history, people have tried to adapt their buildings with the harsh climate in the hot-dry zone through reducing heat impacts (Mohamed, Osman et al. 2010). They used to open their houses onto a private internal open space that visually and acoustically separated from the outside called Sahn "courtyard" (Afify 2002). The courtyard helps in maintaining cooled indoor temperatures by employing the phenomenon of the stack effect (Wazeri 2002). Stack effect occurs when the air inside a vertical stack is warmer than the outside air (provided that there are both inlet and outlet openings). The warmer air will rise and will be replaced at the bottom of the stack by cooler outside air (Szokolay 2014). With some modifications to the courtyard such as using water and vegetation in its landscape, the benefits of the thermal performance could be maximized.

With the development of architecture and technology people have neglected the traditional architecture in terms of techniques. One of these marvellous techniques is the Takhtabush (Figure 1, Figure 2 and). It is an important component of the Arab house which ensures a steady flow of air by convection. Since the backyard is larger and thus less shaded than the courtyard, air heats up more readily there than in the courtyard. The heated air rises up and draws cool air from the shaded courtyard through the Takhtabush, creating a steady cool breeze (Fathy 1986). Figure 3 illustrates the created air flow through the Takhtabush.

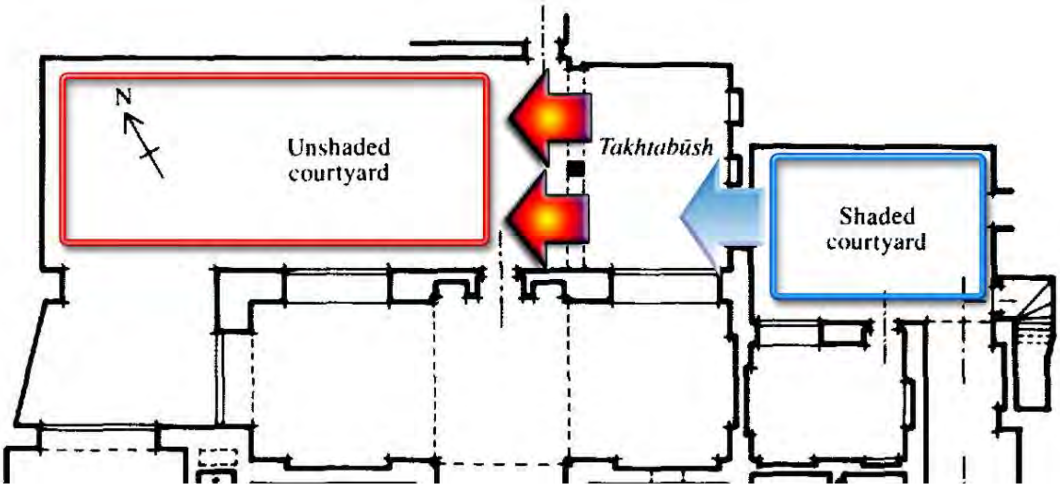

Figure 1: Plan of the part of the ground floor of the Qã 'a of Muhib Ad-Din Ash-Shãf 'i AlMuwaqqi at Darb Al-Usta, Cairo, showing two courtyards with a Takhtabush between them, by the author after (Fathy 1986)


Figure 2:The Takhtabush of al-Souhimi house, Cairo, (captured by the author)

The original houses could be considered an exception in nowadays urban environment with the high density urban areas. However, the concept of the Takhtabush still can be applied on new small houses through different techniques. Since, the required large area for the backyard could be replaced by the solar chimney. Mohamed (2017) confirmed in a previous work the effectiveness of utilizing the solar chimney to replace the large backyard in the Takhtabush system.

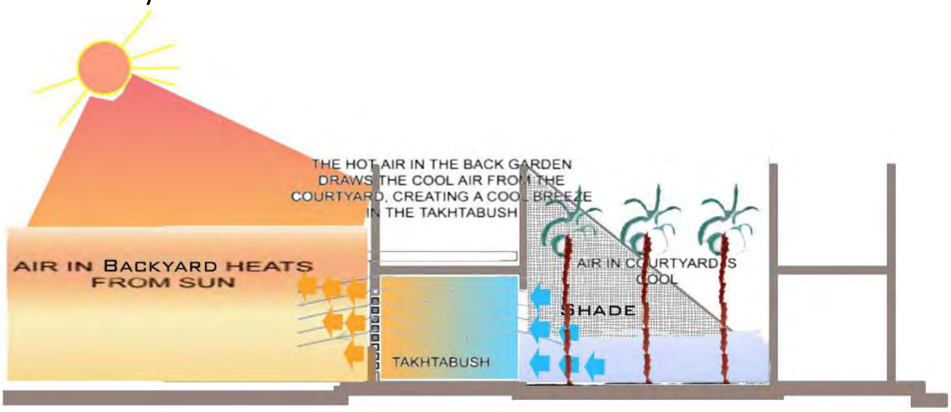

Figure 3: The air flow from the shaded courtyard to the backyard through the Takhtabush, by the author

Research Aim and Objectives

The research aims at quantifying the effectiveness of the Takhtabush on the thermal performance of the courtyard, through the following objectives:

1. Analyse the importance of the Takhtabush through the literature review;
2. Test the performance of two courtyards representing the proposed scenarios (with and without the Takhtabush);
3. Compare and analyse the results of the two scenarios.

Research Methodology

The current research conducts a comparison study between two scenarios of the courtyard (with and without the Takhtabush) through technical investigation. Two courtyards of two different precedents representing the two scenarios, located in the same climatic region (Cairo, Egypt) are monitored at the same time to compare their thermal performance. The two case studies are: Buit Al-Souhimi (The one with a Takhtabush) and Gamal El-Din Al-Zahabi House (The one without a Takhtabush) (Figure 4). The two courtyards are almost similar also in dimensions, height, and vegetation. This is to assure that the variations in the measurements are affected mainly by the existence of the Takhtabush.

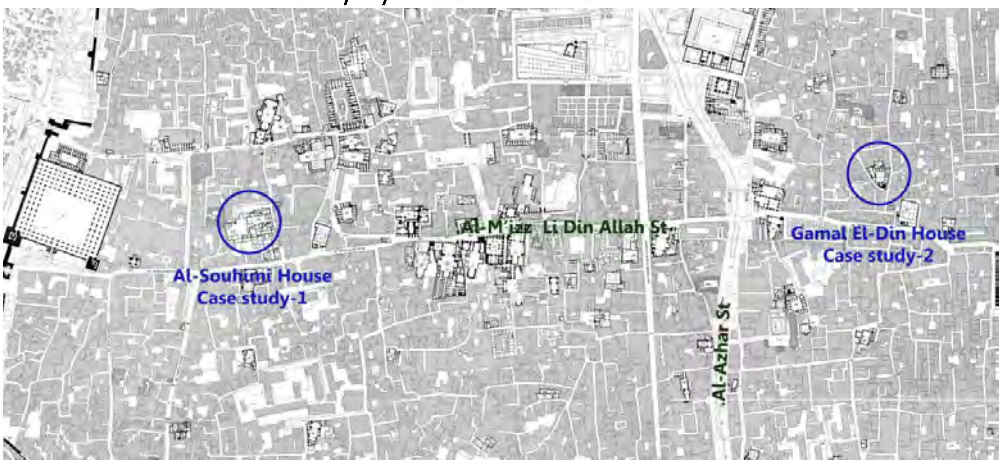

Figure 4: A map of Old Cairo shows the location of the two case studies, after (Warner 2005)

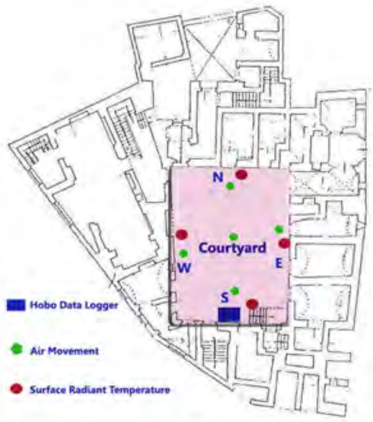

Figure 5: The ground Floor of Gamal El-Din House showing the location of the measurements, by the author

Objective assessment was done using observation and field monitoring techniques Figure 5 and Figure 6 show a ground floor plan for each house with the location of the different measurements inside the courtyards. The measurements included;

1) Monitoring the air temperature of the two courtyards – as the most representative indicator for thermal performance – and the Relative Humidity (RH) using Hobo Data Loggers

H12[1] (**Error! Reference source not found.**). The Data loggers were fixed at the middle of the two courtyards on the same wall orientation (The southern wall[2]) for the whole summer season (from 21-June to 21-September). The time interval was 15 minutes;

2) Data is analysed using statistical analysis software SPSS to quantify the difference in thermal performance between the two courtyards through Mann-Whitney U test[3](Hague and Harris 1993).

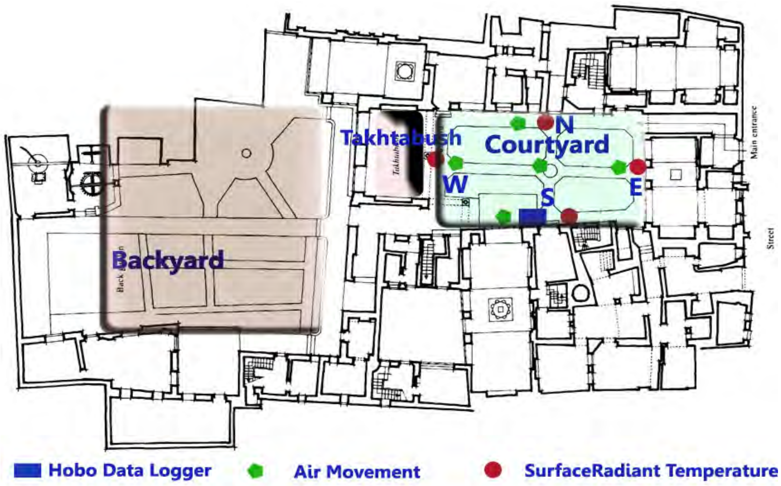

Figure 6: The ground Floor of Al-Souhimi house showing the location of the measurements, by the author after

3) Measuring the Plain Radiant Temperature of the surfaces using MicroRay Pro Infrared Thermometer[4] (Figure 8), and the air movement (wind speed) using Hand Held Anemometer-Sky Master[5] (Figure 9) over different points inside each courtyard for the one daytime on interval of 30 minutes. The 21st of June was selected to represent the worst case scenario, since this day is one of the hottest days over the whole year in Cairo. The noon time from 12:30 to 16:0 O clock, was chosen to represent the hottest time during the day. This will help later to measure the Predicted Percentage of Dissatisfied index (PPD) which predicts the percentage of occupants that will be dissatisfied with the thermal conditions (ASHRAE 2013). It is a function of the Predicated Mean Vote (PMV) using the Psycho Tool. The latter is an electronic version of the psychrometric chart[6] on which human comfort, air-conditioning strate.

Figure 7: Hobo Data Logger H12

Figure 8: MicroRay Pro Infrared Thermometer

Figure 9: Hand Held Anemometer- Sky Master

[1] Hobo Data Logger H12, a device to log the air temperature and relative humidity at certain intervals for a period of time, shown in **Error! Reference source not found.**

[2] Since the courtyard is opened to the sky and receive sun radiation which affect the data logger readings, the only side that is not receiving any solar radiation during the whole day is the south wall that facing the north direction.

[3] Mann-Whitney U test is like t-test but does not require the assumption of normal distribution for the values of the two samples

[4] MicroRay Pro Infrared Thermometer, a device to measure the air velocity at a time

5 Hand Held Anemometer- Sky Master, a device to measure the radiant temperature of a surface by Laser techniques

[6] A psychrometric chart is a graph of the thermodynamic parameters of moist air at a constant pressure, often equated to an elevation relative to sea level

The PMV/PPD index predicts the thermal comfort of people in a given environment. It employs both the environmental and human factors that affect the thermal comfort, and has become the most widely used index in recent years (Mohamed 2009). It has been adopted in the British, European and International standard (HSE 2006). According to ASHRAE (American Society of Heating, Refrigerating, and Air-Conditioning Engineers) these indices combine the influence of air temperature, mean radiant temperature, air movement and humidity with clothing and activity levels into one value on the thermal sensation scale Figure 10 (ASHRAE 2005). The PMV index may be defined as the mean value of the votes of a large group of persons, exposed to the same environment with identical clothing and activity (CIBSE 1999)

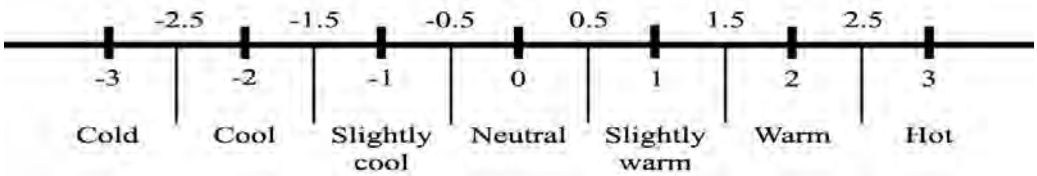

Figure 10: The thermal sensation seven-point scale, after ASHRAE (ASHRAE 2005)

Predicted Percentage of Dissatisfied (PPD) predicts the percentage of occupants that will be dissatisfied with the thermal conditions. In the PPD-index, people who vote -3, -2, +2, +3 on the PMV scale, are regarded as thermally dissatisfied (INNOVA 2004)

Results and discussion

The air temperature degrees of the two case studies were monitored for the whole summer season on 15 minutes intervals. The temperature degrees ranged from 24°C to 46°C. The average temperature for case study-1 (Al-Souhimi house) was 28.46°C while it was 29.56°C for case study-2 (Gamal El-Din house). On comparing the air temperature degrees of the two courtyards by applying Mann-Whitney U test on the air temperature data for the summer season (21st June to 21st September), the results revealed a significant difference ($P<0.05$)[7] between the two case studies, despite the two sets of data trends being consistent. Table 1 presents the statistical analysis output from the SPSS software.

Table 1: Statistics comparison between the hourly air temperature degrees of the two courtyards

Comparison Item	Al-Souhimi	Gamal El-Din
Mean temp.	29.09	30.57
T- Test	P=0.03	
The difference between the two sets of air temperature at the two courtyards (S=Significant)	S	

Figure 11 shows the air temperature for the two cases on a selected day (21st June). The graph clearly presents the significant difference between the thermal performances of the two courtyards. The temperature degrees for case study-1 (Al-Souhimi house) ranged from 25°C to 35°C while it ranged from 27.5°C to 41°C for the other case study. It is obvious that the highest difference between the two case studies is occurred during the noon time. To understand this behaviour, it was important to measure the radiant temperature on the surfaces of the courtyards and the air velocity inside the courtyards.

[7] In the majority of analyses, an alpha of 0.05 is used as the cut-off for significance. If the p-value is less than 0.05, this confirms the hypothesis that there is a significant difference between the means. If the p-value is larger than 0.05, this proves the Null-Hypothesis of no significant difference exists Hague, P. and P. Harris (1993). Sampling and Statistics, Kogan Page.

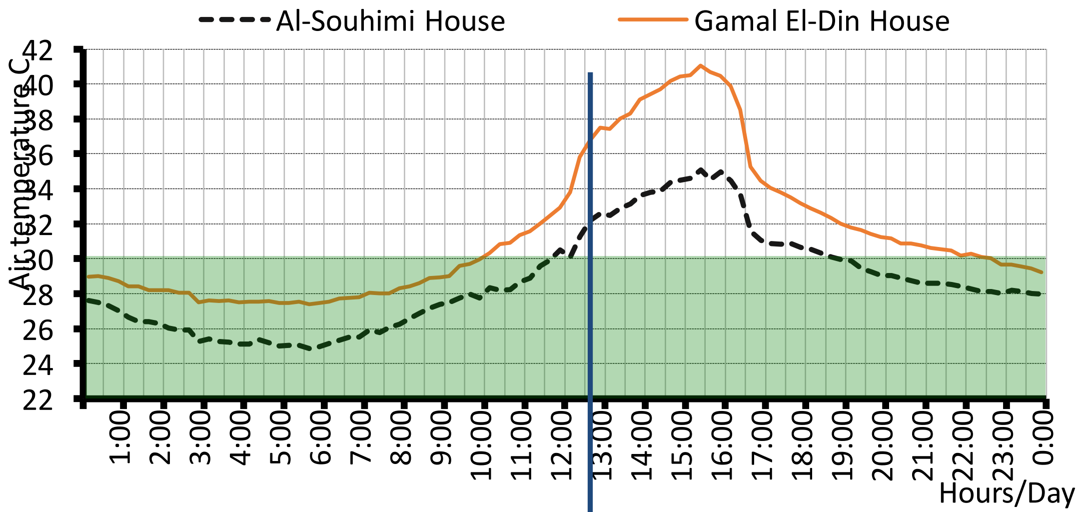

Figure 11: Air temperature of the two courtyards on 21st June for the whole day

Table 2: Surface RT and RH of the two courtyards at 12:30 pm

Surface RT	**Al-Souhimi House**	**Average RT**		**Gamal El-din House**	**Average RT**
North	31.8	29.7		32.6	31.05
East	28.6			30.2	
South	29.7			31	
West	28.8			30.4	
Relative Humidity RH	41%			37%	

Table 2 shows the SRT (Surface Radiant Temperature) and the RH (Relative Humidity) inside the two courtyards of the case studies at 12:30 pm. The average Surface Radiant Temperature SRT at Al-Souhimi courtyard is 29.7 °C which is lower than the average SRT at Gamal El-Din courtyard by 1.35. The relative Humidity RH at Al-Souhimi courtyard was 41% while it was 37% at Gamal El-Din courtyard.

Table 3: Wind velocity at the two courtyards from 12:30 to 16:00 afternoon

Wind speed	**Al-Souhimi**									**Gamal El-din**							
North	1	0.9	0.7	1.1	1.6	1.4	0.8	0.3		0.6	0	0.3	0.5	0.4	0.5	0.5	0.3
East	0	0.5	0.6	0.5	1	1.1	0.9	0.2		0.3	0.2	0.3	0.6	0.3	0.5	0.4	0.3
South	0.5	0.7	0.8	0.6	0.6	0.5	0.5	0.3		0	0	0	0	0.3	0.2	0.2	0.4
West	1	1.2	1.1	1.4	1.6	2	1.2	0.9		0	0.6	0.1	0	0.3	0	0	0
Centre	0.9	0.9	0.8	0.9	1	1.1	1.0	0.9		0.4	0.1	0.5	0.6	0.5	0.5	0.6	0.2

Table 3 presents the wind velocity at the two courtyards at intervals of 30 minutes from 12:30 pm to 16:00. The measurements were taken at different five points as shown before in Figure 4 and Figure 6 which are at the four sides of the courtyards in addition to the middle points. It is evident that the air movement inside Al-Souhimi courtyard was higher than Gamal El-Din courtyard most of the time, if not all the time. This confirms the efficiency of the Takhtabush in accelerating the air velocity inside the courtyard. In addition, it explains the differences in the surface radiant temperature of the two courtyards, since the air movement decreases the surface radiant temperature from the construction.

Figure 11, reveals a significant decrease in the air temperature during the noon time at case study-1 compared to case study-2. Based on the results of the SRT and the air velocity, it is evident that the phenomenon of the stack effect that manages to create a steady cool breeze between the shaded courtyard and the backyard through the Takhtabush works successfully at Al-Souhimi house.

In order to quantify the effectiveness of these differences of measurements on human thermal comfort, the PMV and the PPD were calculated for the two case studies on 21st June at 12:30 pm. Figure 12 and Figure 13 present the PMV and the PPD for occupants inside the two courtyards at 12:30 pm on 21st of June. The clothing level was assumed 0.6[8] clo which refers to light clothes (trousers and shirt), while the occupant activity was assumed 1.5 met (metabolic rate[9]), which refers to standing occupants with light activity with metabolic rates ranging from 1.2 met to 1.5 met.

Although both values of the two case studies show discomfort levels for the occupants because of the chosen time from the year and the day, it is clear that the thermal performance of the Al-Souhimi courtyard is better than the other case study. While PMV was 2.7 on ASHRAE Scale for Gamal El-Din courtyard, which represented HOT thermal condition for occupants, it was 2 for Al-Souhimi courtyard which represented WARM thermal condition for its occupants. As for the PPD; it was 97% for Gamal El-Din courtyard which means that almost all occupants would be dissatisfied at the that time, while it was 75% for Al-Souhimi courtyard which means that not all occupants are dissatisfied, where 25% of the occupants are satisfied with the thermal condition.

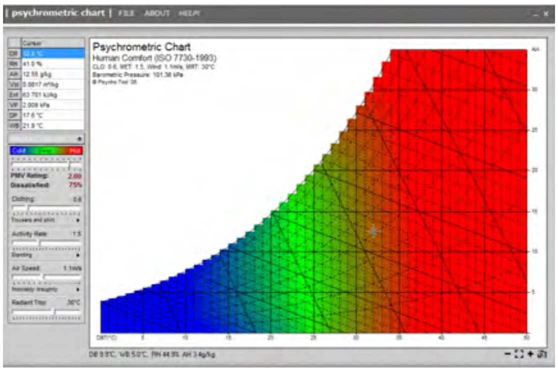

Figure 12: PMV and PPD for occupants at Al-Souhimi courtyard at 12:30 on 21st of June using the Psychrometric Chart

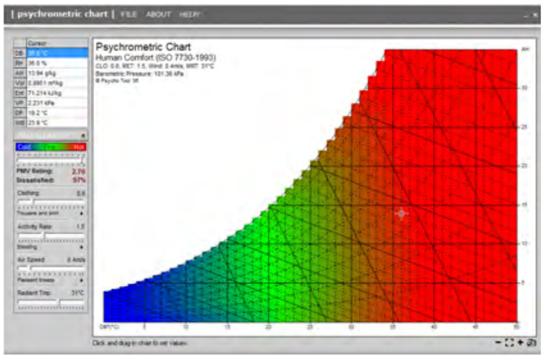

Figure 13: PMV and PPD for occupants at Gamal El-Din courtyard at 12:30 on 21st of June using the Psychrometric Chart

Conclusion

An objective assessment for two scenarios of courtyards in old Cairo was carried out in this research. The two courtyards were almost architecturally similar to each other except the attached Takhtabush which exists in the first case study (Al-Souhimi house) and does not exist in the second case study (Gamal El-Din house). Air temperature, RH, Air velocity, and Surface RT were monitored and measured during the same times and intervals. PMV and PPD for occupants were evaluated based on the collected data. On analysing the measurements, it was obvious that the thermal performance of the first case study (courtyard attached to Takhtabush) was much better than the second case study (courtyard without Takhtabush). This has been shown clearly through the following results:

- P-Value was <0.05, revealed that there is a significant difference between the air temperature degrees inside the two courtyards during the summer season (21st of June

[8] 1 clo = 0.155 m^2 °C/W, where m = area, C = degrees Celsius, and W = watts

[9] The metabolic rate characterizes the energy generated inside the body due to metabolic activity. The standard unit for metabolic rate is the **met**. 1 met = 58.2 W/m^2 (18.4 BTU /h ft^2)

to 21st of September);

- Air temperature degrees inside case study-1 are much lower than case study-2 and particularly during the noon time because of the steady air flow caused by the Takhtabush;
- PMV and PPD were much better in case study-1 than case study-2 by about 25% which confirms the effectiveness of employing the concept of the Takhtabush in today's designs in the hot zones of the world.

Acknowledgement

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Aesthetic analysis of vernacular architecture of Rajwar of Central India

Shikha Patidar[1], Vasumati Savant[2], Eti Sharma[3]

[1] Vinyas, A Group of Artist, Architects and Engineers, Bhopal, India
[2] The American Institute of Architects, New Jersey, The United States of America
[3] Smt.Dhariya Prabhadevi Sojatia Women's College, Indore, India

Abstract: India is known for its embedded rich culture and heritage. In India, especially in rural areas some of the communities have a unique settlement pattern and architecture due to climate, topography and availability of materials. The culture and architecture are closely knitted with each other. The architecture of *Rajwar* community of Central India has a unique style. It is the finest example of bas–relief architectural ornamentation in India. The paper aims to study the aesthetic aspect of the vernacular architecture of *Rajwar* community of Central India. The objective is to understand the social and cultural aspect of this community and its reflection in architecture. The methodology adopted is to document and analyse the aesthetic aspect of the vernacular architecture of this particular region. Documentation is done in the form of sketches, drawings and photographs. The experts and artisans are also interviewed. The aesthetic analysis is done on different aspects of visual art forms namely sculpture, painting, bas- relief, design patterns and colours which are inbuilt in the construction. Paper concludes that the architecture of *Rajwar* community is a true reflection of their culture. The ornamentation is not mere a decoration but a ritual representing their beliefs and way of life.

Keywords: Vernacular, Architecture, *Rajwar,* Ornamentation, Aesthetics

Introduction

India has a rich tradition and culture which reflects in its vernacular architecture. In the vernacular architecture of Central India, the architecture of *Rajwar* community is unique in its style. It is the finest example of bas-relief architectural ornamentation in India. Such architecture survives only because of its beauty and aesthetics. Its tradition is still transferring from one generation to another. Due to its architectural character, it can be easily identified that this village belongs to *Rajwar* community. In its basic form and space planning it is not different from other vernacular architecture of the region but in its ornamentation, it is entirely different.

"*Rajwar* houses are amongst the finest example of rural aesthetic sensibility for, though decorative, they have an austere beauty and simplicity about them. Beautiful lattice work in clay adorned with simple figures all painted in white and subdued colour give the house and auspicious aura" *(Shah*, 1996:95).

The population of *Rajwar* community is around 600,000 and is widely spread in Chhattisgarh, Madhya Pradesh, Bihar, Jharkhand, Orissa and West Bengal. In India, it is densely populated in *Sarguja* district of Chhattisgarh. In Chhattisgarh, this community is found in village namely *Ambikapur, Baikunthpur* and *Surajpur.*

Figure1. Map of India

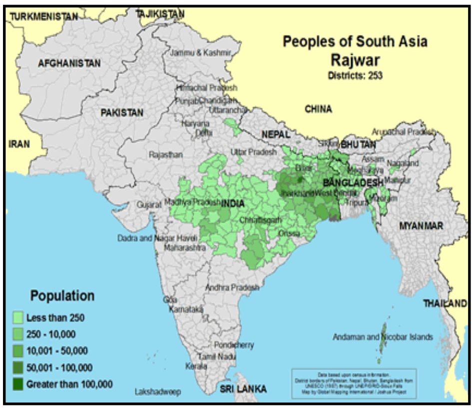

Figure2. Map Showing Population of *Rajwar*Source:https://joshuaproject.net/assets/media/profiles/maps/m1

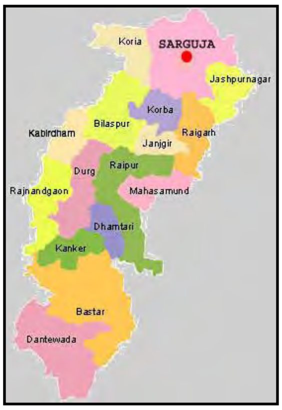

Figure3. Map of Chhattisgarh

Aims and objective

The paper aims to study the vernacular architecture of *Rajwar* community from Chhattisgarh, Central India. The objective is to understand its social and cultural aspect of this community and its reflection in the architecture. Analyse the aesthetic aspect of the vernacular architecture of this particular community of this region.

Methodology

The methodology adopted is to document and analyse aesthetic aspect of the vernacular architecture of this community. For the case study selected a *Rajwar* dwelling constructed by *Sundari Bai* and *Pandit Ram* at Indira Gandhi *Rashtriya Manav Sangrahalaya*(IGRMS) (National museum of Man) Bhopal, observed and also studied Exhibition at visual Art Gallery at Tribal Museum at Bhopal and Tribal Art Gallery at *Bharat Bhavan*, a multi- arts Complex Bhopal, India. We witnessed the construction of documented dwelling, interacted with artisans and learnt the techniques of making lattice with mud and bamboo, relief work and terracotta decorative roof tiles. The documentation is done in the form of sketches, drawings and photographs. Observed different visual art forms sculptures, paintings, bas-reliefs and analysed different design patterns which are in practice**.**

In *Sarguja* district of Chhattisgarh, the villages exhibit some of the finest bas- relief architectural ornamentation in India. In most of the rural villages, women sculpt clay bas-relief on the walls during the construction. The style of sculptures in these regions is from extremely minimal to highly complex. This unique style is known as *Sarguji.*

Figure4.&5. Construction of *Rajwar* dwelling, IGRMS, Bhopal Source IGRMS

Figure6. *Rajwar* dwelling, IGRMS, Bhopal all four side views Source *Abid Baig*

Planning

Rajwar dwellings usually are formed around a courtyard surrounded by a columned veranda, of which radiates kitchen, bedrooms and store room. Grain bins sometimes used to segregate spaces. Usually, there is only one door and no windows outside. A small typical rural dwelling is taken for case study at IGRMS. There is no courtyard in this dwelling. In front and left side there are verandas. On right and back side there are no doors and windows.

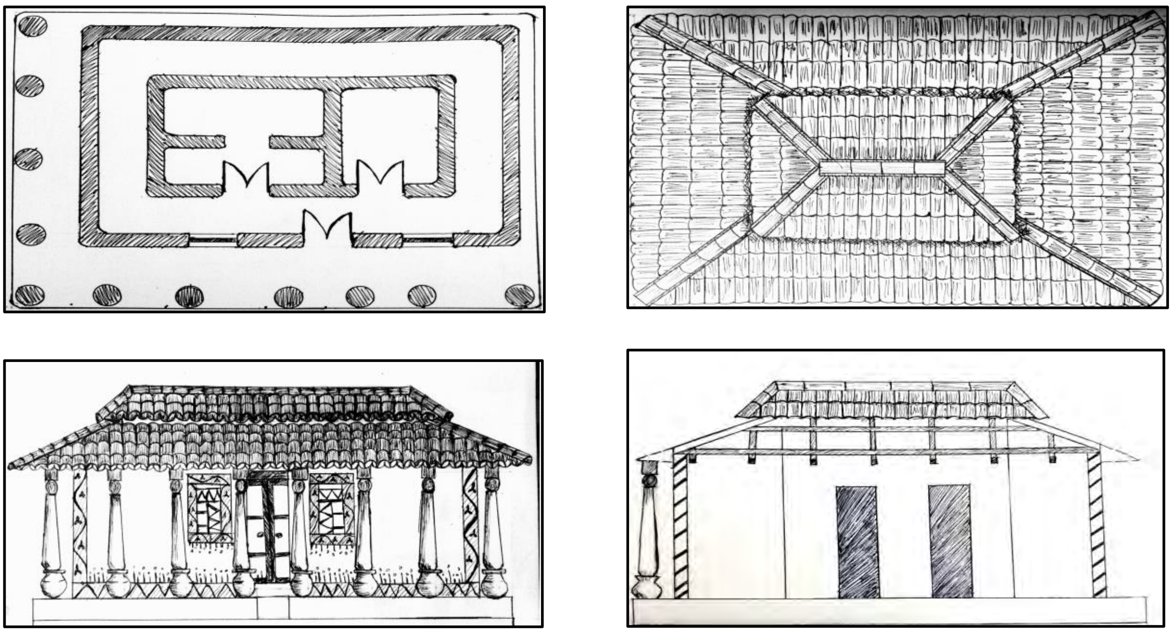

Figure7. *Rajwar* dwelling IGRMS, Bhopal Ground Plan, Roof Plan, Elevation and Section Source *Kirpa John*




Figure8. IGRMS,Column Figure9. Grain Bin Figure10. Door Figure11. Window Source *Vikas Patidar*

Construction

It is common in Indian villages all the members of the family contribute and collaboratively construct their dwelling right from procuring the material till finishing. All the dwellings in this region are constructed in a similar manner using locally available materials and techniques. Although they are constructed in the same manner still each one is different in its style. The dwellings are decorated when they are first built, again when rooms are added and on the special occasions on festivals like Diwali. Before starting their work they pray let all the elements of cosmic world, nature, animals, God and Goddess adorn their house.

Walls

The foundation is made of random rubble masonry. The wooden pillars are placed on wooden or stone pedestal of the unique shape of a pot and beams held with decorative capitals and brackets together (Figure8) Adobe wall is made with mud mortar, clay, cow dung and straw. The interior walls are decorated with bas- reliefs depicting images of their activities of day to day life (Figure18) dance forms, landscapes, fields, house, animals, God-Goddess. They are painted with different natural colours. Some of the walls are painted soft white interlaced finger pattern of lines *Leepan* (coating) (Figure27) horizontal, vertical, diagonal or curved named after the shapes they resemble.

Doorways-windows

The doorways (Figure10) and window frames (Figure11) are decorated with simple designs made up of clay that the simply sculpted design and patterns around the perimeter of the front door and painted with red, yellow ochre or black so that it stand out against the whitewashed walls. The pigments are made with different vegetables herbs spices and minerals. Bright green made of leaves, the yellow mixture of spices and minerals, red ochre from red oxide, black made from black clay and burnt leaves and blue from indigo is used.

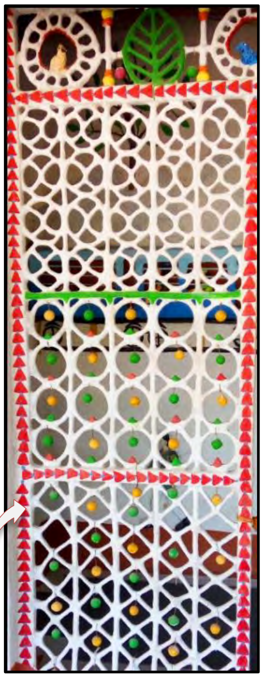

Figure12. *Sakarpara*

Figure13. *Dharibani*

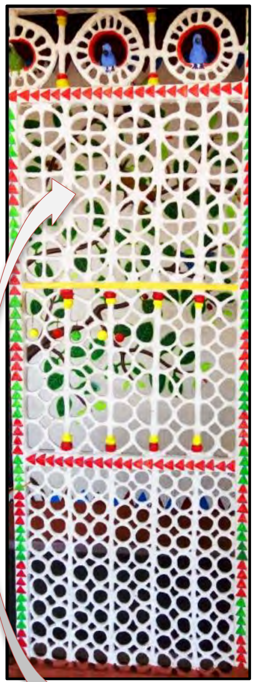

Figure 14. *Seekabani*

Figure 15. *Machlikanta*

Lattice

To soften the light and lessen its intensity screen, made of bamboo and mud is created in the veranda. This screen, the lattice is called *jali* (Figure12) which is created between the width of supporting pillars of the veranda and the height between the roof beam and the floor. It is made up with a thin bamboo strip cut and tied together to build a simple grid in the space. Then strips from another piece of bamboo curls into the round circle fasten each other with a small piece of twine and joined them all between the grids. To create the screen the clay added to the edges and bamboo circles smoothen into the rounded supports and blended the entire screen into the surface of the pillars.

The sculptures are made by rice straw tied tightly with the string and supported by bamboo sticks covered with wet clay smoothen to get the desired form after drying it is painted with bright colours the images of people (Figure18) animals (Figure19). Some sculptures toys, dolls, animals, insects and idols of God-Goddess are made of bamboo and clay enhance the beauty of the lattice. The images of Goddess *Saraswati, Laxmi, Durga* and God *Ganesha,* Hanuman (Figure24) and Krishna (Figure25) are introduced for particular festivals like *Dussehra, Diwali* etc. These sculpted lattices create a light and shadow effect in front of recessed niche and shelves. In the designs of lattice intricate geometric pattern are created with parallel, criss-cross, diagonal, zigzag and circular lines. These patterns are simple and complex too. Some designs are repetitive some are the combination of two-three forms.

The decorations are done all around the dwellings on the edges of the courtyard, on the steps, in the verandas, in the kitchen, bedroom and store room and even on the Grain bins. Auspicious symbols drawn on walls and floors during the festival, rituals connected with seasonal changes sowing of crops, harvest or special occasions of the family such us birth puberty, marriage, pregnancy and death these symbol drawn afresh each time.

Figure16. *Ghar* (house)   Figure17. *Rail* (train)   Figure18. Man with a plough   Figure19. Woman working

Aesthetic Analyses

Rajwar art tend to free itself from the constraints of naturalism, this art derives its substances from nature, depicting birds, animals, trees does not render it in a natural manner. By observation the design patterns found in architecture of *Rajwar* are named after its resemblance to the objects of surrounding like house, basket, temple, grain bin etc. Design patterns found in this vernacular architecture style are following;

Kothi (Grain bin Pattern) (Figure9): This pattern is evolved from grain bin used for keeping grains. The grain bins are decorated with bas- relief.

Shakarpara (Diamond Shape) (Figure12): This pattern is evolved from *Shaker para*, a sweet dish made in a diamond shape. It is formed by a crisscross of diagonal lines.

DhariBani (Line Pattern) (Figure13): These design patterns are made spontaneously with the movement of fingers. The walls are painted with a unique style. In this design pattern parallel vertical and horizontal lines cut each other and from rectangular and square grids. In some patterns, diagonal lines crisscross each other.

SeekaBani (Basket Pattern) (Figure14): These design patterns are evolved from different bamboo baskets weaving patterns. It is clearly reflected in these designs.

MachliKanta (Fish Bone) (Figure15): This pattern is evolved from fish bone usually placed in the centre of the design and on the borders.

Ghar (House Pattern) (Figure16): The image of a hut is also used in paintings and bas- reliefs. The shape of the pitched roof is used as an element of design.

GhiriyaBani (Lizard Pattern): From the movement of moment of lizard *(Giriya)*, this pattern is evolved. The rhythm of the movement is visible in this from.

MakarBani (Spider web Pattern)**:** This pattern is evolved from spider's *(Makar)* web. It is similar as network of fine threads constructed by a spider starts from small to larger polygon in ascending order.




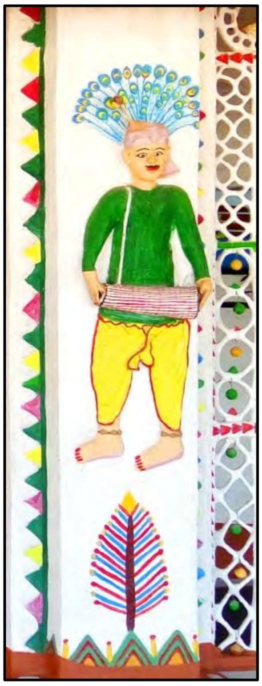

Figure20. Bas-relief,Elephant Figure21. Peacock Figure22. Snake Figure23. Dancer Source Author

Naag Bani (Snake Pattern) (Figure22): This pattern is evolved from the movement of the snake. This is mostly found in borders and on columns.

Chhohaleepan (Coating Pattern) (Figure27): These design patterns are made spontaneously with the movement of fingers. The walls are painted with a unique style.

Phool (Flower Pattern): This simplified foliate design pattern is evolved from the articulation of different followers.

Results and Findings

Aesthetics is a sense of perception. It is concerned with the nature and appreciation of art; beauty and good taste. Judgement of aesthetic value relies on sensory, emotional and intellectual level. According to German philosopher, Immanuel Kant-beauty is objective and universal. But beauty may be subjective and varies according to class, culture, background and education. The aesthetic judgements are culturally conditioned to some extent The Indian art evolved with an emphasis on inducing spiritual or philosophical states in the audience, or with representing them symbolically. In analysis *Rajwar* art fulfils the criteria of aesthetics given by the contemporary American philosopher, Denis Dutton. He has identified seven universal signatures of aesthetics

- **Expertise** - technical artistic skills are cultivated, recognized and admired
- **Non-Utilitarian Pleasure** - people enjoy art, and don't demand practical value of it
- **Style** - artistic objects satisfy rules of composition that place it in recognizable style
- **Criticism** - people make a point of judging, appreciating and interpreting works of art
- **Imitation** - works of art simulate experiences of the world
- **Special Focus** - art made a dramatic focus of experience
- **Imagination** - artists and their audiences entertain hypothetical worlds.

Figure 24. God *Hanuman*

Figure25. God *Krishna*

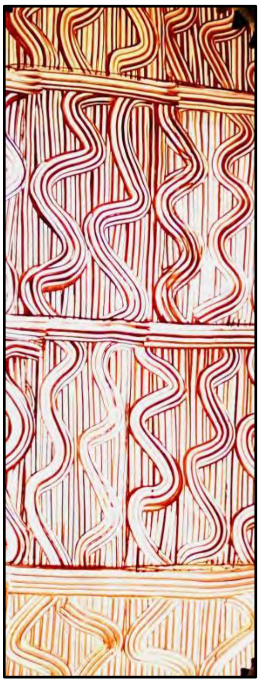

Figure26. *ChhohaLeepan*

Figure27. *ChhohaLeepan*

Conclusion

Architecture of *Rajwar* community is a true reflection of their culture. The ornamentation is not mere a decoration but a ritual representing their belief and way of life. Aesthetically it is a unique style embedded in architecture. Such integration of art and architecture is missing today. With this aesthetic sensibility contemporary architecture can also flourish.

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PLEA 2017 EDINBURGH
Design to Thrive

The study of architecture of Gond Tribe of Madhya Pradesh, India

Shikha Patidar[1], Brishbhanlali Raghuwanshi[2],Eti Sharma[3],

[1] Vinyas, A Group of Artist, Architects and Engineers, Bhopal, India
[2] School of Planning and Architecture, Bhopal, India
[3] Smt.Dhariya Prabhadevi Sojatia Women's College, Indore, India

Abstract: In the 21st century, it is observed that a lot has changed in terms of Indian tradition and culture in every aspect. Sadly, this has cut the roots of the knowledge system of architecture developed by our ancestors To hide the dying blossom of traditional vernacular architecture, it is being loaded with artificial aesthetics, which forms a false image of the rich culture of India. The tribes in different parts of India are still living with their traditional knowledge system. The architecture truly reflects their culture, lifestyle, ethics and aesthetics which give special and unique character to it. The aim and objective of the study are to acknowledge, understand, observe and draw the inference from the study of the vernacular architecture of Gond tribes of *Umariya* district of Madhya Pradesh. The different types of settlement patterns of some villages are studied. The locally available material, method of construction and traditional knowledge system will be studied. The methodology adopted is to document and analyse the selected typologies. The result and findings focus on learning lessons from traditional knowledge. The paper examines some key assumptions for policy makers in planning and designing of appropriate housing and planning strategies for different tribes.

Keywords: culture, vernacular, architecture, tribe, Gond, sustainable development

Introduction

The tribes all over the world have distinct features in terms of culture, lifestyle and architecture which showcase their way of life and how they celebrate it. These characteristics have developed distinctly in all tribes over a period of time. They live in forests far away from city life and hardly mingle among each other. These distinct features can be easily seen in Gond tribes residing near *Umariya* district of Madhya Pradesh.

The Gond tribes are the largest tribal Community in India and are Dravidian's whose origin can be traced to the pre-Aryan era. The word "Gond" comes from the Dravidian expression Gond, meaning "the green mountain". For example tribal living in a village *"Chandiya"* they make their house using sun-dried bricks. They use soil in different stages of construction. Soil strengthens and beautifies the house. They have excelled the art of building simple abodes with the more natural process without harming the environment. Through their hard efforts, over thousands of years created rich and colourful styles of vernacular architecture, responding to the local environment. The reason for more percentage of tribal in the states can be attributed to the geographical locations like islands, rivers and mountain ranges.

Figure 1. Gond Tribes

Figure 2. Gond Paintings

Figure 3. Gond Dances

Figure 4. Map of states of India

Figure 5. The population density of Gond settlement in India

Figure 6. Map of M.P.

Aim and Objective

The aim of the study is to know about the tribal ethics and the aesthetics and understanding their ways of living develop a symbiotic relationship between them and the natural environment. Tribes nurture from the natural resources but at the same time safeguard forests and other natural resources. The main objective of the study is to observe their lifestyle and culture, analyse architecture and aesthetics. The documentation includes the study of settlement pattern and typology, considering construction technique, planning, aesthetic and response to climate and the surrounding environment.

Methodology

To learn about the Gond settlements patterns and their dwellings of some of the villages coming under district *Umariya* were studied. Villages *Ufri*, *Bhagda* and *Mahroi* were taken as case studies. The different typologies were observed and in the village *Amanhudi* the dwelling of *Ashok Singh Tekam* has been taken as a typology to study the planning and construction. The documentation is done in the form of sketches, drawings and photographs.

Figure7. Village

Figure8.Village Street

Figure9. Community space

According to the 2011 Census of India in Central India, the state of Madhya Pradesh has the highest population of tribes, which constitutes the 20.26 % of the total population of the state. Gond is the second largest tribe, with a population of 4,357,918 constituting 35.6 % of the total ST population of the State.The tribal population is 46% of the total population of *Umariya*.

The area of study is *Umariya* district, amongst 47 districts of Madhya Pradesh comprising of 660 villages surrounded by Jabalpur district from the west*, Katni* district from the north*, Shahdol* district from the east and *Mandla* district from the south. The district lies between north latitudes 23° 05' and 24° 20' and east longitudes 80° 40' and 81° 17', with a geographical area of 4503 sq km. The physiographic features include Northern Valley area, Central-Plateau area and Southern Hilly area. The southern part of this district is represented by hilly terrain, which is the northern part of *Amarkantak* hills extending in East-west direction. The highest elevation of the district is located on the southern boundary of the district near village *Singhpur* having an elevation of 980 m above mean sea level, comprising of basaltic rocks. The northern part of the district in *Manpu*r block area there is prominent valley which, almost originates from the Achaean hills and extends north wards. Major drainage is *Son*, *Johila* and *Choti Mahanadi* river.

It has abundance of mineral resources including coal and clay. Commonly found rocks are Granites, Sand -Stones, Slates, Basalts and Alluvium. Major soil type found is laterite, clay and loamy soil. It is also full of natural resources. About 53% of the area that comes about 765 acres of land is covered with forest and the rest 47 % comprises of the total sown area is 1604 acre and cropped area is 1941 acre. Common crops include paddy, maize, wheat, mustard, gramme pulses. Common trees found in forests are Teak, Haldina cordifolia, Madhuca Longifolia, Shorea Robusta and Mango. Bamboo is also found in abundance.

Climate

The Climate of this district is characterized by a hot summer and general dryness, except during southwest monsoon season. The year may be divided into four seasons. The cold season spans from December to February, followed by the hot season from March to the middle of June. The period from the middle June to September is the south- west monsoon season followed by post -monsoon or transition period in October to November.

The Gond tribes live their life within natural surroundings secluded from the outer world, with no dependence on any other community. This leads to a special and distinct character. in the evolution of settlement and the development of the architectural elements and prominently in terms of culture and traditions.

Figure10. *Devlook* (Deity)

Figure11. *Parchhi* (Verandah)

Figure12. *Kothi* (Storage)

The Gond tribes decorate their dwellings with vibrant depictions of local flora, fauna and gods such as *Marahi Devi* and *Phulvari Devi*. Traditionally made on festive occasions such as *Karwa Chauth*, *Diwali, Ashtami* and *Nag Panchmi.* The oral tradition of stories, anecdotes and folktales are very popular among them. They sing and dance on the occasion of birth and marriages. In some instances, such as with the *Dandari* dancers, dances re-tell events from Gond mythology. At other times, dances are performed simply for fun. *Dhulias* are a professional musician caste and *Pardhans* preserve legends, myths, and history, passing these traditions on from generation to generation. They have rituals and beliefs associated with trees, most villages have scared spaces under the trees. Trees with medicinal values are Ficusreligiosa, Ficusbenghalensis, Vachellianilotica.

Traditionally Gond tribes are agriculture labours, sand collectors of forest produce. They depend economically on crop produce from agriculture and little craft items and daily use items like the broom, baskets, mattresses, jewellery etc. They use bamboo, grass and mud and other easily available material to make these crafts. These distinct features of the Gond tribes not only depend on the cultural aspect but also on topography, climate and availability of materials.

Types of settlements

Settlement pattern according to contours

The growth of village is organic and the road determines the basic spatial form in which the village is evolved. In the village, the dwelling units are placed with respect to landform in a manner that the streets allow to drain the rain water during monsoon. They depend upon forest produce for their livelihood. [1]Unlike the tribes living in plain areas. their dwellings are also scattered They live in clusters of three to four houses and even these clusters are at different levels away from each other because of undulating landform. These clusters are not connected by defined pathways as the houses are constructed in the fields itself, for example, village *Ufri.*

Figure 13 . Settlement pattern of a Gond village named “Ufri” according to the contours

Scattered settlement

The second type of settlement is comparatively smaller, the number of dwellings goes up to 30. These settlements are the satellite of the nucleolus village. They have a non-linear pattern of settlement. A group of 4- 6 houses are built together forming a place of social cohesion in the centre. But these houses also have the same concept of the backyard which is connected to the farms. As the family expands village becomes dense. Once the settlement reaches the maximum number of houses a new settlement in the vicinity is set up.

Figure-14. Scattered settlement of a Gond village named *"Bhagda"*

Compact Planning

These villages are located on plains and the average size of the village is 100-150 houses. This settlement acts as the nucleus for the small tribal settlements which are on the periphery at the distance from 2 to 10 km. The growth of village is organic and the distinct impression is made by the road which connects the village with other villages. The placement of the houses is more linear and compact. The connectivity of pathways is in accordance to the pedestrian that is why it has acute turnings and fewer junctions. [2]The pathways have houses on both sides with the same concept of backyard connecting the farms. For the social gathering, huge open spaces are left between the house lanes. This open space is multifunctional. It is the centre place where the market, fairs during festival and rituals are performed throughout the year. It is often known as "*Chupal*".

Figure-15. Compact settlement of Gond village named "Mahroi

Dwelling layout

From the study done on the Gond settlement, it is clear that these tribes make an effort in integrating the spatial, social and ritual perspectives and ultimately leading to a habitat which amply represents in their dwelling which varies depending upon the location, occupation, community and the micro-climate.

Dwelling plan

The house studied was a Gond farmer with 6 family members. This house has a rectangular plan with central courtyard used as a multipurpose space for all the day today activities. All the rooms are planned along the courtyard connected though a semi-open veranda. It is a free space which is used as a sleeping area and also for cooking and storing things. The entrance is an intricate welcoming semi- covered veranda called "*parchhi*" with black pillars supporting the roof used as a common interacting space where the neighbours or visitors gather. As we enter the house, there is an enclosure which is used for different purpose like keeping vehicle's, crop from farms and is also used as sleeping space for guests. The enclosure on the left side is semi-open is used as an animal yard. On the right, there is a kitchen, "*devlok*", space for the deity. ''*Kothi*' granary made of mud and straw is also used as a partition in living spaces. There are two rooms in the back-side of the house used as sleeping space.

Figure16. Elevation and Section

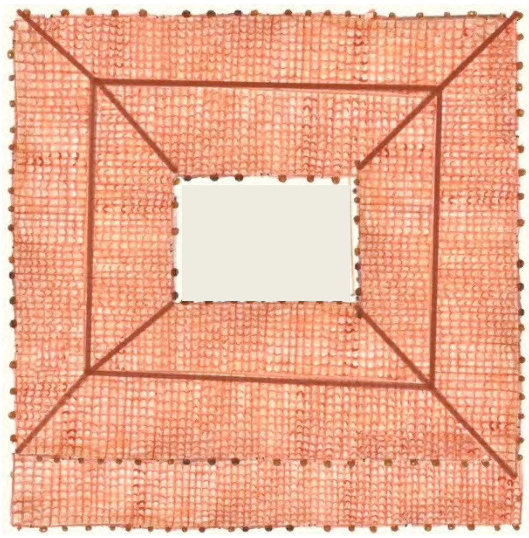

Figure17.Roof Plan

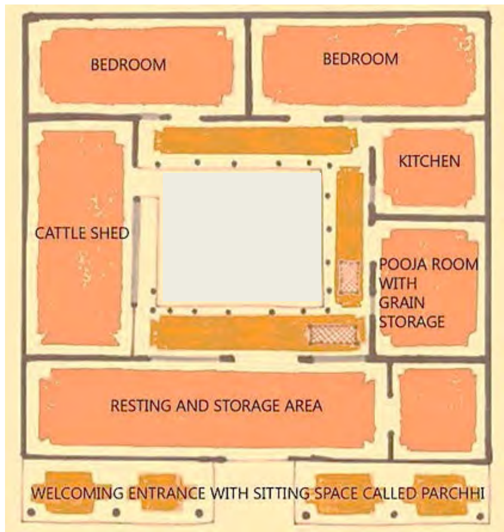

Figure18. Plan

The roof type is lean-to roof for semi-open space with supporting member of timber columns. The openings have door panels only on the external walls. For ventilation, small vents are provided on the external walls. There are no openings on side walls all windows open in the courtyard. Pitched roof covered with terracotta tiles. Reeds are used for partitions.


Figure19. Wooden post on pedestal


Figure20.Mud Wall


Figure21. Roof

Construction

The main building material used for constructing the load-bearing walls of the dwellings was Adobe, since mud is the most plentiful resource in the region. Adobe units are made of mud, which can be found on site, mixed with straw along with water. The wall is on an average 300mm thick and has small niches called *"aale"* used to keep *"diya"* (oil lamps) or other useful items. The walls also have inbuilt racks beautifully decorated with relief work. The walls are hand-plastered with same mixture of mud and husk used in adobe units. After hand plastering the walls, they are beautifully painted with different coloured clay- red, yellow ochre, white and black.

The roofs are hipped, double lean and lean-to roof. The roofing is done with terracotta tiles, which are good insulators also. The load-bearing walls support the roof frame placed above. The main horizontal member is of timber on which king post along with the whole truss rested. The Eaves of the roofs are projected along with the length of the house. This projection protects the erosion of mud wall during rains and also provides sunshade. The temporary structure for cattle is constructed with four wooden posts and thatch roof. The lintels are of timber planks or stone members. For ventilation, rectangular voids are left in the walls. Bamboos are used as grills in case of large openings. In veranda, the adobe units are laid to form inbuilt furniture which can be used for sitting or storage.

Though some variations in construction techniques were observed in different villages during the research, for example, the tribes in village *Chandiya*, use sun-dried bricks for construction of walls in their houses. The size of the brick is 3"x6"x12".

Aesthetics

The Gond tribes do not give much height to their building which reduces the traces of built-up area in the skyline. The doors and windows are beautified by painting using different coloured clay. Bold borders are painted along the walls and floor. Elaborated relief work done using clay enhances the aesthetic appeal of the house. They mostly use geometrical shapes like triangles, circles and squares which form beautiful patterns. Some other relief works also depict their life and nature. The houses are decorated with paintings depicting animals, birds, trees and folklores. The Gond tribes believe that a good image brings good luck. This inherent belief led them to decorate their houses and the floors with traditional motifs. The Gond pradhan tribes of Mandla district developed entirely a different painting style which is known as Gondi art transformed on papers and canvas.

Figure22. Outside Door

Figure23.Veranda

Figure24. Inside Door

Result and findings

Common features observed in the selected Gond settlement-:

1.) The settlements have the single resource of water which is a river, waterfall, spring or a community well. There is no provision of sewerage in those settlements. The wastewater is directed into the backyard.
2.) All the houses are facing the pathway and have a backyard or farm land. The pathways leading to the houses are in accordance to the contours, and they are undulating and haphazard. They are narrow and do not have lot of intersections.
3.) Gond Tribes follow different pattern within the same geographical location. This variation is mainly due to topography, microclimatic condition and their occupation.
4.) Gond paintings are an integral part of their culture in which they depict beauty of nature and observations from daily life. But no such paintings were seen there.
5.) Present day construction is not in synch with the vernacular architecture which the tribes practise.

Conclusion

The Gond tribes developed a symbiotic relationship with nature. The existence of tribes has become an important attribute for maintaining a balance in ecology. According to the development traits seen in the present sinerio there is an urgent need to change the methods. One must consider the ethics and methods the tribes have adopted for construction and strictly adhere to it. To maintain this system there is a need to understand the tribal way of living and provide appropriate planning and design using their knowledge .

Acknowledgements

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Design to Thrive

THE ADOBE Educative video for a locale culture

Amanda Rivera Vidal[1,2], Cristian Muñoz[2]

[1] Escuela de Construcción ECoT, Santiago, Chile, amandariverav@gmail.com
[2] Rivera+Muñoz, Santiago, Chile, riveramunoz@gmail.com

Abstract: The educative video "THE ADOBE" is the result of a research made on the centre of Chile. It has been made after a large earthquake which took place the 28 February 2010 in the central zone of Chile. This zone is the most urbanized that concentrated 90% of the population of the country. This event has deeply marked the memory of the Chilean people. The video shows and highlights the knowledge of the inhabitants of this territory, and looks to strengthened a constructive culture: the technique of mud brick. In central Chile, a third of the population lives in earthen dwellings today. In Chile, the adobe brick is the most used technique of earthen construction. It is part of its heritage, its past and also its future. Although this material is very present in the landscape, it fell into disuse and oblivion. Unfortunately, its implementation remains the most stigmatized and the least studied.
The educational video so provides knowledge to combat this ignorance on the construction of adobe and promote this heritage. It is a manifesto to save this constructive culture.

Keywords: mud brick, heritage, earthquake, vernacular construction, Chile

Introduction

The adobe is one of the techniques that have accompanied the man from his sedentary settlement, which manifests itself in a universal way adapting to its conditions. The adobe, in its apparent simplicity, has existed for two millennia (Noriega & Vauzelle, 2014).

Chile has been founded on adobe constructions, being the union of the native technology with the culture brought by the Spanish conquerors that settled in the south of the American continent during century XVI, establishing the main urban centres "from the valleys of the *North Chico* and Concepción"(Benavides, 1988). This culture later expanded to the whole territory known today as Chile, from the North to the Patagonia.

Chile and the earthquakes

Chile is located at the south of South America, between the Pacific Ocean and the Andes Mountains, geographical limits that are the evidence of the confrontation of the tectonic plates that generate the recurrent seismic movements which characterize its culture. Chile is one of the most seismic countries in the world, where large earthquakes have occurred in the past and will certainly cause major earthquakes in the future (Barrientos, 2010).

Figure 1. House in the epicentre of the earthquake of 2010 (-35.951561, -72.743889), contrast between occupied, restored, maintained and neglected housing. Trehualemu (Chile), 2016.

The last earthquakes - 2005 of 7.8Mw in Iquique; 2007 of 7.7 Mw in Tocopilla; 2010 of 8.8Mw in Cauquenes; 2014 of 8.2Mw in Iquique; And 2015 of 8.4Mw in Coquimbo - that have affected Chile have struck large areas of territory, extensive and traditionally built with raw earth blocks. Although there is no accurate data on the amount of adobe buildings or, therefore, on the percentages of adobe dwellings damaged by these earthquakes, it is estimated, according to data from the Inventory of Cultural Heritage Property prepared by the Architecture Department of the Ministry of Public Works, that about 40% of the official heritage declared sites are built on earthen techniques predominating the raw earth masonry and the mixed techniques of wood and earth (Contreras et al, 2011).

After each event, there has been a lack of knowledge about traditional constructive cultures, which are adapted to the central characteristic of the territory: earthquakes. Although in the Chilean territory the immense majority of the heritage constructions is built in adobe the knowledge of professionals, both their existence and technical-constructive specifications are few. Even if the oldest building of the colonial time: the church and convent of San Francisco located in the main avenue of the capital Santiago, not to mention the immense amount of vernacular heritage scattered throughout the territory, are built with mud brick.

In spite of the growing interest of professionals for the earthen construction and technologies, the wide presence of contemporary constructions with the material and the nascent activities of diffusion of these material in the country; as well as different initiatives at the international level to promote earthen construction, recognizing that earth has been, is and will be one of the main materials used by mankind to build their habitat and shape their habitat, and that at least a quarter of the world population lives today in earthen houses (World Crongress TERRA, 2016). There is a systematic marginalization of the study on the traditional and vernacular technologies that have built the Chilean identity, which has generated not only a generalized ignorance in the national professionals, but also a stigmatization and widespread rejection towards the old constructions, thus forgetting the traditional technologies that, through the trial and error of centuries, have mixed native technologies with a Spanish foreign technique adapting it to the Chilean seismic territory through various strategies and intelligences (Figure 1).

Earthen constructive typologies

From north to south of a country with 4329 km length, there are different expressions of popular earthen architecture. In the arid north of Chile, where stone, earth and cactus are the only building materials, earthquake resistant strategies are based on the geometry of buildings. In the central and southern regions, where temperate and cold climates allow the growth of large trees, wood reinforcements are the most frequent earthquake resistant solutions (Jorquera & Pereira, 2015), demonstrating the adaptation of the culture to geographical diversity.

The different earthen techniques are rather mixed constructions, where the earth together with other structural elements, like the wood, compose the constructive system; or only earth techniques, such as mud brick and rammed earth, where the structural element is the earth (Muñoz & Rivera, 2012)

Mixed constructions earth and wood

The large quantity of wood transported aboard ships in the northern hemisphere during the 19th century resulted in the creation of a wooden carrier system filled with blocks of land called "adobillo" (Jorquera & Pereira, 2015). This system is delivered with all its splendour in the hills of the city of Valparaiso. It is a prefabricated system mainly generated by the abundance of soil suitable for the execution of the earthen blocks, but not at the same place of the port but on the hind slopes. Thus a method to fabricate smaller blocks (50x15x10 cm) was created to facilitate transport. This system consists in anchoring the earth blocks to the wooden support structure thanks to the shape of the block which prevents the movement of the blocks at the dynamic moment from the plane of the wall. It is essential that the blocks are anchored on both sides of the wooden structure (Figure 2a).

This system is replicated in different parts of the country with some variations, incorporating appliances and mortar between the blocks, which allow the separation of the vertical structure. It is generally used as the secondary structure in adobe constructions.

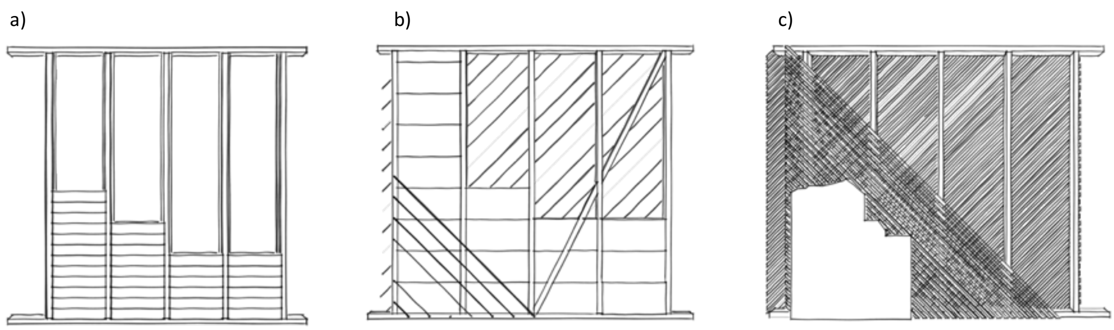

Figure 2. Traditional mixed earth and wood constructions: "adobillo", "pandereta de adobe" and "quincha"

As a complementary system and commonly found as a secondary structure of adobe constructions there is the constructive system called "*pandereta*" or "*adobe parado*" because of the use of the same adobe block, usually 60x30x10 cm, placed on edge (Figure 2b). This typology is still found as a secondary structure for filling a wooden supporting structure to which the blocks are not anchored, but bonded by steel wires and less frequently by wooden slats. This system is used recursively to make internal divisions or floors. Traditionally, its structural logic compels it to be separated horizontally by wooden pillars, in order to avoid the weaknesses of the disunity of the blocks (Rivera, 2016).

The seismic and native construction system for excellence in this field is the "*quincha*", the quechua[1] name for the wattle and daub technique (Figure 2c); when in a territory with abundant plant resources. This works with different woods as a primary and secondary structure, abundant in the second elements of the materials of least resistance such as the branches or minor section bamboo. This system of construction is not limited to the humble constructions of indigenous peoples, but has been reproduced and used in constructions of Hispanic influence, mainly in the port cities. It was used in the first towns of the territory when it was the local workers who built "we made our wooden and straw houses in the track that gave them" (Benavides, 1988).

Earthen massive constructions

The rammed earth and *adobón*[2] are two systems of construction in earth mass that is mainly like a delimitation of the land or the habitat for the animals. It is used in some northern cultures to build human dwellings but is more used as exterior boundary. Both are manufactured in the site and in its final location, with a thickness around 50cm or more. The difference between them is the consistence of the filling mixture, the firs one uses a humid mixture and the second a plastic one, thus with more water on it. In these systems, there is a necessary overlap between the blocks (Rivera, 2016).

The construction system par excellence found in the foundation of the towns and villages is the adobe. Over time and nearly 500 years since its implementation, it has incorporated different strategies, to try to circumvent the problems associated with earthquakes.

EL ADOBE, the mud brick

The adobe is a raw earth block formed by hand or moulded in plastic state, and then dried in the air. Compared with other earth-building techniques, brick masonry is synonymous with a very fast execution, comparable to that provided by industrial materials. The adobe is extremely economical, even in developing countries, where blocks and construction are almost tool-free (Anger & Fontaine, 2009).

The construction in adobe is a universal system, which in Chile is expressed with proven seismic components, is the sample of an evolution in the resolution of problems of sustainability and construction pertinent with the local environment and culture. It is a system not only suitable for heritage, but also for sustainability and the future, and has been tested against the earthquakes of greater magnitude of the planet. The adobe, is the ductile instrument of the whole peasant construction, based on the empirical handling of the behaviour of the materials in front of the earthquakes.

It is observed in traditional architecture that for the correct behaviour of simple masonry structures there are a series of rules that buildings which have already undergone several earthquakes. This represents the state of the art and it is essential to give importance to the complete structural analysis of constructions. The geometry of the buildings reveals that the main requirement is that buildings should be simple for greater seismic stability. The building must have symmetry in terms of mass and rigidity, both in plan and elevation, to

[1] Native South American language family spoken primarily in the Andes
[2] Known as a big adobe build on site

reduce torsional stresses; a slight slenderness, in order to reduce the tendency to tilt; and a compact plane with a low ratio of height and length, to have similar resistances in each direction. Homogeneous façades with floors of the same height and a low centre of gravity can also reduce the vulnerability of the building. The number of openings should be reduced, carefully and symmetrically distributed (Correia et al, 2015). Each strategy exists with its own intelligence and technological development of a given moment, which progresses and evolves towards the best resolution of the generated problem, for stability in the face of earthquakes. The strategies are complementary and crossing them represents a behaviour far superior to the movement.

Along the Chilean territory, that covers 4,000 kilometres (2,500 miles), different adobe cultures emerge, according each one to the local resources, the cultural influences and the natural environment. At the north, where vegetation is rare, the structural performance is based on the mass strategy (Figure 3a). This gives great importance to the thickness of the wall. The adobe construction has a minimum slenderness radio of 1:8, making the traditional walls at least 50cm thick. In spite of that, walls of 60cm are are the most frequent, because the most common raw block measure is 60x30x10 cm (236”x118”x39”) where its length becomes the thickness of the wall. At greater heights, the walls increase to 90cm (354”), 120cm (472”) and up to 150cm (590”) thick, measures that arise from the modulation of block (Figure 4).

Another structural strategy present un the country are the counterforts, that are external wall elements that support them and counteract the seismic efforts. They avoid the walls overturns and give the stability. They are used mainly on churches, where there is a great wall length with a lack of interior support elements (Figure 3a).

a) b) c)

Figure 3. Different adobe cultures from the north to the south as a demonstration of its context. Pachama Church in the Atacama Desert, a house in Petorca in the central zone and a house in Puerto Guadal in the Patagonia.

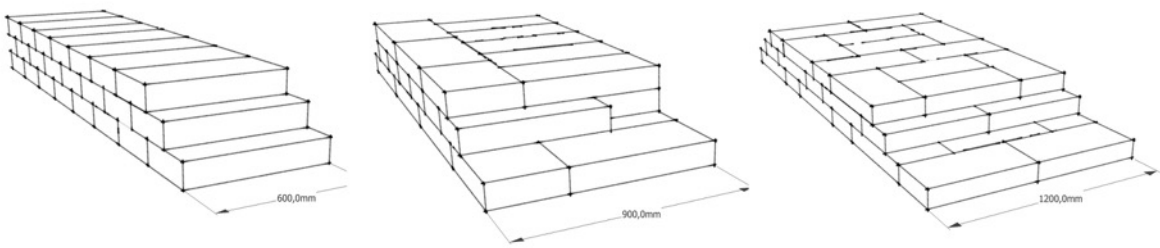

Figure 4. Different raw brick rigs with 60x30x10cm block. 60cm, 90 cm and 120 cm of thickness of the wall.

In the central zone of the country, from the zone of the “Norte Chico” until de Bio-Bio river, their is a culture of wooden reinforcement which help adobe constructions with the dynamic moment, because of is flexibility, lightness and deformability without reaching breaking point. These reinforcements are horizontal wooden, placed along the construction as horizontal ladders called "*llaves*" (Figure 3b) or in critical zones such as the join of two walls called "*esquineros".*

One of the newest abode cultures of the country is the austral one, which began 100 years ago, when some northern communities arrive to this lands. In this zone, because of the lack of earthquakes, the seismic parameters are absent. The adobe constructions are mixed with wooden roofs (Figure 3c), being the mixture of the abundant elements available in the territory (Jorquera & Rivera, 2015).

Educational Tool

To re-educate about the ancestral and more massive construction system of Chile is the main objective of the educational tool, which is expressed in the form of video to expand the audience to which it is wanted, becoming an instrument easily accessible and understanding. Destined to builders, authorities, academics, professionals and the inhabitants of adobe houses, it aims to re-educate, especially to build and understand the adobe constructions.

Building in adobe should be an integral exercise: understanding, restoration, reinforcement, completion, maintenance, reconstruction and habitat should be understood as a whole, to ensure its endurance in time and adequacy to contemporary needs properly. Despite the enormous number of examples of adobe buildings compatible with the largest earthquakes in the world, national information and studies are scarce; So the work begins with the premise of finding information from the same terrain: buildings and builders. The development of educational initiatives in the area affected by the earthquake of February 2010 has since been the main work of the team; Repairing, training and valuing local knowledge and materials. And it was there that can rescue the main amount of information for the construction of an effective educational tool and layers to disseminate and value constructive technique through the delivery of tools for its repair and reuse (Figure 5).

Foreign reparation experiences are taken, such as the investigations of the Pontifical Catholic University of Peru and its application to the Chilean case through electro welded meshes. But above all, it seeks to put in value the health and constructive intelligence of traditional adobe systems, which, based on three basic elements (earth, straw and water), have faced great movements and changes.

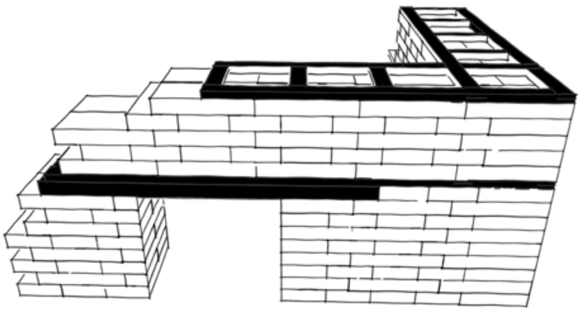

Figure 5. Illustrations of the educational video. Explanation of the incorporation of wood elements to the masonry of raw earth.

Educational video

The educational video "EL ADOBE" is the result of research conducted mainly in central Chile after the earthquake that affected this area in 2010. The audio-visual document is focused on adobe construction and seeks to represent constructive culture local of this territory, with its knowledge and constructions. Systematizes experiences, seeks to promote as a viable alternative the repair of adobe constructions and socialize the knowledge about techniques suitable for their care and maintenance. It is an educational tool of wide scope of geographical and temporary way; Transporting in a faithful way what happened in reality.

The video begins with the Chilean national context of construction in adobe, making a concise tour of the territory evidencing the presence of the material in cities and towns. Then it goes into the technical narrative by transforming this cultural route into its constructive manifestation: Chile's different earthen building techniques, their differences and structures, is where it focuses on Chile's most massive technique: on the construction in adobe. The story begins with the manufacture of the raw earth block: its materials, forms of realization and measures; to continue with the way of arranging these blocks for the creation of spaces: the masonry of adobe. To help the current reality of construction in adobe, the most frequently encountered damages are posed and then possible repairs; always contextualized in the Chilean reality and its seismic context. The video was developed with the main support of different professionals with extensive experience in the construction and repair of raw masonry. And it was developed jointly with the Rivera+Muñoz producer, the Jofré Foundation and financed by the National Council of Culture and the Arts (Ministry of Culture).

Figure 6. Exhibitions of the video in cities and towns affected by the 2015 earthquake on the northern of Chile. Canela 2015 and Combarbalá 2016.

Dissemination and implementation

After the realization of the educational video from the year 2010 to 2012, a diffusion was made in different networks, mainly between academics and professionals. Distinguishing between them the cycle of presentations made in 2013 to six universities from Iquique to Concepción. After that the main tool of diffusion has been through the internet where the video can be seen and download, which already has more than 13 thousand reproductions since its launch in 2015, which demonstrates the interest in acquiring knowledge in this subject.

Despite the enthusiasm of the authors for the massive diffusion of the information and therefore their complete openness to the use of the material, it was only until after the earthquake of Coquimbo of September of 2015 that it was verified the usefulness of the tool, as a method of easy transfer of information. The projection of the video, first in the square of Canela (the epicentre of the earthquake) was the opening to deliver knowledge both to professionals and local inhabitants, who have used the knowledge delivered for the development of repair and rebuilding of the affected area. Then the replication of this activity in different communities of the region (Figure 6) has had a large and important impact, where copies have been distributed massively, where the message has been transferred and used.

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Lessons from the Shikumen of Shanghai

Rachel Simmonds [1]

[1] Interior Design, School of Design, University of Edinburgh, Edinburgh College of Art, rachel.simmonds@ed.ac.uk

Abstract: This paper looks at the Shikumen housing in Shanghai, and explores the aspects of its unique character that can inform design to form, support and retain communities in today's expanding urban landscape. Unique to Shanghai, the Shikumen, built in the mid 19th Century, were speculative developments housing workers. Their layout, of a main alley with branch alleys off, formed city blocks and communities. Their typology, signified by the stone gate entrance, inner courtyards and hierarchy of internal spaces, created communities within communities. With the development boom in Shanghai, the Shikumen are being demolished. Some have been retained, but mostly in a pastiche form that supports non housing uses such as shops and restaurants. Only recently has the importance of their original function within families, communities and the wider city been realised. This is not being supported by any programme of retention or preservation. This paper will analyse the Shikumen to extract those important elements that are relevant to the development of Shanghai, and housing on an international scale. It will make a comparison with the Colonies housing in Edinburgh, housing of similar form and age, that has not only been retained, but is being reproduced in a modern form.

Keywords: Shikumen, Colonies, Housing, Communities

Introduction

In 1842 the Treaty of Nanjing turned Shanghai into a treaty port. As it opened to trade from foreign countries, concessions began to be formed in the city to house the British, Americans and other Europeans living there. The Taiping Rebellion of 1850-64, resulted in refugee from the countryside moving to Shanghai, dramatically increasing the number of people living in the foreign concessions. This population explosion resulted "in the need for new accommodation and a new housing type, the alleyway house was developed to cater for this need" (Bracken: 2014). This emerging new housing typology is commonly known as Shikumen. The translation of the word is stone gate, and refers to the distinctive architectural entrance feature of the houses. They were originally commissioned and owned by foreign investors and have been described as being formed from "hybrid architectural styles that testify to Shanghai's unique history of colonial capitalism, industrialisation and cosmopolitanism "(Li: 2014). They were built from 1870 – 1940, and this paper deals with those from 1870-1910, known as the old style stone gate Shikumen (Bracken: 2012). It should be noted that these "foreign real estate owners relied on Chinese compradors to supervise Chinese contractors and manage the construction and rental of their properties "(Liang: 2008). There is "little evidence to support the view that the alleyway house is a hybrid of Eastern and Western building traditions", and that the builders of the Shikumen “may have copied some western details but that is as far as this hybridity goes. (Their) genesis is clearly Chinese “(Bracken: 2013).

There are however, typological similarities between the Shikumen and a housing typology in Edinburgh of the same era. So whilst they were not a direct influence on each other, how they have evolved over the past 150 years, highlights key elements that should be considered in lessons to inform design that forms, support and retain communities in today’s expanding urban landscape.

Elemental Analysis of the Shikumen urban block

It is important to understand their wider urban importance, before looking at aspects of the houses themselves. Shikumen were built in terraces, usually running east to west, with the main entrance to the house on the south side, with the secondary kitchen entrance on the north side. These rows form a series of secondary alley ways (approximately 3m wide), all of which run perpendicular to the main alley (approximately 4-5m wide). The houses to the perimeter of these lanes enclose it, thus forming an urban block. A typical block can contain around 100 houses (Bracken:2013). Entrance into the block is via one or a series of metal gates on the perimeter. These are typically open during the day but locked at night. The buildings forming the boundary tend to have shops on their ground floor and face out towards the surrounding streets. This protective barrier for the housing inside embeds the block within the wider urban context, and encourages engagement with the perimeter shops by those living out with the immediate community.

This creates an urban typography that supports a hierarchical series of spaces moving from public (surrounding streets), semi-public (main alley), semi-private (secondary alleys) and private (Shikumen themselves, including their courtyards).

Figure 1. Typical Shikumen Lane, Shanghai (photo: R.Simmonds)

Elemental Analysis of the Shikumen House

A typical Shikumen house from the mid 1880’s – circa 1915 is a two storey courtyard house, entered via a wooden door in a large stone gateway in the external wall. Passing through the gate you immediately are in a small courtyard. From here you enter directly into the sitting room of the house. This is where guests are welcomed and main family events take place. Leading off from each side of the sitting room are the wing rooms. One would have been used as the study for the man of the house, the other as a bedroom for the grandparents. When Shikumen were first built they housed a multi-generational family group, which was key to their success in supporting and retaining the communities they formed. Behind these is the stair to the first floor, and behind that a kitchen with small courtyard and stores. Above the kitchen, off the half landing of the stair is a small bed room, sometimes referred to as the garret (Zhang: 2011) or the tingzijian (Shanghai Xiantiandi). It was often rented out to a non-family member such as a scholar. On the second floor are the remaining family bedrooms for parents and children. This layout maximises habitable space by focusing circulation to a core at the centre of the house.

From 1870, they were typically constructed of masonry and timber, following the prohibition of completely wooden houses by the Shanghai Municipal Council (Zheng: 2011). The exterior walls are brick, sometimes with a white wash or cement covering. The gable walls to the main lane are often ornate and highly decorated. The key feature of the stone gate had ornate pediments and sides. The double leaf wooden door that sits within it is traditionally painted black and has large iron or bronze ring handles on each leaf. The roofs are terracotta pan tiled. All windows are timber framed and single glazed, with those looking into the courtyard being full height, often with semi ornate timber tracery. Exterior windows to the north and south elevations have slatted shutters. Each house therefore is dual aspect, but with a clearly defined front and back.

Internally the courtyard serves the dual purpose of improving ventilation in the house, and bringing light in to the interior. The internal staircase is timber, as are the screens that divide the wing and upper rooms, or form wall panelling in key rooms such as the sitting room (Sheng:2011). The internal walls were painted white.

Factors Influencing the Decline of the Shikumen

The decline of the Shikumen has been due to several factors. On 01 October 1949 China became a communist country. The Shikumen came under state possession and became collective property (Li: 2014). The communist government distributed the Shikumen to people for low rent. This resulted in up to seven families being housed in accommodation that had previously only contained one family. The low rent also meant that there was no money for maintenance, and the houses began to fall into disrepair (Tsai: 2008). The removal of owner occupier status also contributed to this decline as there was no one directly responsible for maintenance living in the house.

Due to their compact urban typology there was little flexibility in terms of expansion (Bracken: 2013). Whilst internally rooms could be reconfigured, there were limits due to the number of people now living there. Subsequently the lack of proper bathroom facilities became a much larger issue. Today the majority of Shikumen remain subdivided to house several families or groups, resulting in insanitary conditions. There are no internal toilets or washing facilities. These are catered for in communal blocks near the perimeter gates.

Construction of Shikumen ceased after the rise of Communism in 1949. At that time there were over 9,000 clusters of them in Shanghai, housing around 4 million people (approximately 80% of the population). Demolition began in the 1990's, and "as land values in central areas continue(d) to soar, whole city blocks (were) earmarked for redevelopment and the people who lived in them (found) themselves forced to move out "(Bracken: 2013). This again removed large amounts of Shikumen from the urban typology. Today its estimated that only around 200,000 people in Shanghai live in Shikumen (Grescoe: 2017), which equates to around 1% of the population.

Conservation of the Shikumen

In 1988, the non-gratuitous transfer of land use rights came into effect in China. Cities like Shanghai got very involved in urban redevelopment, (Yang & Chang: 2007). Unfortunately, a robust conservation policy was not equally established. In 1991 the Shanghai Municipal People's Government issued measures for the preservation of historic buildings in the city that divided them into three categories: nationally important cultural relics, cultural relics of Shanghai City and historic buildings of Shanghai city. This was slow to recognise the Shikumen. It wasn't until 2003 that the first local law for historic heritage preservation, The Preservation Regulations of Historic and Cultural Districts and Historic Buildings in Shanghai City was created. (Tsai: 2008). Unfortunately, "resolving the conflict between development and preservation presents a large challenge, especially when the historic significance of historic heritage is not well understood and the power of investing capital is predominant. (Tsai: 2008).

In the late 1990's, the 52-hectare site, known as Xiantiandi, in the city's Taipingqiao area, was redeveloped by the Luwan District Government and some Hong Kong based developers (Yang & Chang: 2007). It redeveloped the Shikumen in the block by retaining their facades and putting high end western focused shops and restaurants behind. Whilst the urban form is retained, it could be argued that the real spirit of the Shikumen has been lost, and in its place a pastiche idea of historic Shanghai remains, that gives a false impression of the hundreds of thousands of visitors, as to what historic communities in Shanghai really are.

Figure 2. Xiantiandi, Shanghai (photo: R.Simmonds)

In relation to the Shikumen the development of Xiantiandi is significant, as it recognised for the first time, the importance of the typology. A few other areas have followed a similar fate with an hotel complex created in one and the Tianzifang area focusing on tourist shops, restaurants and creative workplaces. Cite Bourgogne is the arguably the best example of Shikumen housing being retained, however its preservation and restoration is not to a level that would be recognised in the west as being protected or restored in any significant way, as they are still housing multiple families in poor condition.

The nature of historical preservation in Shanghai is highly pragmatic. Historical architecture is preserved not for its value as cultural heritage, but for the potential economic return. (Ren: 2008).

Background to Colonies Housing in Edinburgh

In 1861 the Edinburgh Cooperative Building Company(EHBC) was formed. Its purpose was to "get working men self-contained houses, where they would have their own front door, every room being independent of the other having a door from the lobby for privacy, and having little green attached to each house, and having everything arranged in a sanitary way" (Pipes: 1998). The first were built in Stockbridge between 1861-1911, on a rural site by the Water of Leith to the North west of the city centre. Known as Colony housing, due to their purpose of forming a community, this housing style is distinct to Edinburgh. There were 11 sites developed in the city by the EHBC from 1861 until 1946, when it ceases trading. (Rodger: 1999). When they were first constructed they attracted artisans and workers. Whilst owned by locals, initial figures suggest that 20% of the occupants were from Edinburgh, with the rest migrants into the city. For their size they were densely populated, with 13% having 8 or more occupants. Owners supplemented their incomes through lodgers, but this led to obvious pressure on space. (Rodger:2011).

Elemental Analysis of Colonies Housing in Edinburgh

The urban typology of the Colonies is one of city blocks formed from "tightly packed panel rows of houses with external balcony access to upper floors" (Rodger: 2011). The houses in each terrace are two storeys high, but the ground floor and first floor properties are accessed from neighbouring streets. This gives each its own private garden area. The upper floor properties are accessed by external stone stairs, with two neighbouring doors sharing an access stair and entrance balcony.

Figure 3. Typical Colonies Street, Stockbridge, Edinburgh (photo: R.Simmonds)

Externally, like most of Edinburgh, they are constructed from sandstone. They have a traditional Scottish pitched slate roof, with simple pitch gable at each end. The main doors are painted raised and fielded style, with a square fanlight above. Each one has a brass letter box and knob. All the windows are single glazed sash and case.

Internally the ground floor flats have a simple layout with a parlour to the front and a kitchen with separate bedroom off to the rear. The kitchen has a sink in the window and also contained a bed recess. The short hall that runs to the kitchen from the front door also has an inside wc and a coal store. The two storey upper colonies flats had a similar layout on their lower floor, but the wc moved to the location of the coal store to allow a stair to the upper floor to be inserted. The sink in the kitchen was relocated to a cupboard off the kitchen. On the upper floor are two bedrooms with former windows to the front elevation.

Conservation of Colonies Housing in Edinburgh

Today the Colonies are listed buildings, with those in Stockbridge obtaining a Category B listing in 1973. This means they are of national significance and any alterations to them required statutory consent.

Whilst initially these houses were home to large family groups, or a mix of home owners and tenants, by the turn of the 20th century things were beginning to change. The original residents had died and those that inherited the original houses did not necessarily stay in them. Today the Colonies are inhabited in a much less dense way. Throughout the city, and particularly in Stockbridge, these houses are now generally home to couples or small family groups. The original community created may well be long gone, but a new urban community is created, largely due to the close proximity of the houses and streets, and the middle class nature of the inhabitants. Stockbridge Colonies, has its own Residents Association, with its own website containing information for new residents and host of activities for residents to engage with. This community interest in their topology has been significant in preserving their form.

Similarities between the Shikumen and Colonies

There are a number of similarities between the two housing types that can be noted. The key one is that their urban form maximises available area by forming a series of tightly packed terraces. The plan of the houses allows for dual aspect, cross ventilation and defined private outdoor space. This hierarchy of public and private spaces is important in defining a community and both integrating and defining it within the wider urban topology. Removing, or in the case of the colonies reducing, the impact of the car on a pre-car typology, has ensured that people can move freely between properties, further supporting community activity and engagement.

A compact plan with minimal corridor space allows for easy movement between rooms, and supports flexibility in how the internal spaces are used, allowing them to accommodate varying numbers of people. Having a defined front door for each residence supports their individuality within the wider density of the urban form. The use of traditional materials ensures that the houses have the potential to be durable, as long as they are regularly maintained.

Both have supported a change between smaller family groups to larger multi family groups, although in the case of the Shikumen it is in the opposite direction to the Colonies, thereby creating more issues for the housing type, as the aging buildings have to tackle more physical demands by the numbers of inhabitants.

Lessons to be learnt on conservation from the Colonies.

The colonies can be considered to have survived for a number of reasons. Their urban density allows for a relatively large number of people to live in close proximity without feeling overcrowded. This is achieved by the splitting of the entrances for lower and upper flats to adjacent streets, thus allowing each property to have its own front door and defined outdoor space. These spaces are green, unlike the Shikumen where courtyards are hard landscapes.

Their construction is important. They were built well of good quality materials such as stone and slate. This has meant that they are hard wearing and, as most of the materials are local to the area or Scotland, can be replaced easily if required. Also their layout allowed for good in-house sanitation for washing and cooking. Whilst the layout was well considered, it allowed relatively large numbers of people to be housed in them initially, and has needed no major changes to support the smaller demographic who live in them today. The fact that there are two sizes of Colonies houses within the same development is also significant as it allows people to stay in the same area as their housing needs expand and contract throughout their lives, something now missing in the Shikumen with the loss of multi-generational family groups under one roof. The communities that they formed were strong and have survived. Today in the Stockbridge Colonies there is support for engaging with neighbours and those out with the immediate family group. Social status of these inhabitants support this, and for the Shikumen if they became aspirational houses then their value would increase dramatically.

Lastly differences in the national conservation policies as noted previously, and the current socio economic status of Shikumen and Colonies has had a direct influence on their differing heritage preservation.

To undertake and support any of the above, in the relation to the Shikumen, then recognition by the Chinese Government of their importance, back up by actual legislation and enforcement of conservation policies, with ensure the sustainability of these unique housing types. It is interesting to see in Edinburgh, over the last 18 years, a series of “Colony Style” housing has begun to appear as a new typology. Most significant of these are the Dublin Street Lane development by Richard Murphy Architects (1999), and the McDonald Place Development by EMA (2016). These new colonies are successful for a number of reasons including creating a sense of community which comes from sharing footpaths, gates and external stairs, use of traditional building materials, having larger windows openings and glass balustrade that give a contemporary feel and restricting vehicular access within the site (Urban Realm: 2015). The evolution of the housing form has not happened with the Shikumen to the same extent as their preservation has not extended beyond the shell of the buildings. Once you significantly alter the interior, especially the general massing, the whole functionality of the building, as a dwelling, is lost.

Conclusions

This paper has reviewed possible ways to conserve the Shikumen housing type in Shanghai, to ensure it plays a positive role in the urban expansion of this vast city. Its historic importance in the city must not be lost, as that would to lose a key part of the city’s character. Whilst their importance has been recognised in recent years, the pastiche retention or reproduction of them, in areas such as Xintiandi, does not go far enough in preserving them in their original way – as communities centred around families.

To support them as housing they need to update elements such as kitchens and bathroom to ensure satisfactory sanitation. Ensuring the quality of the external shops will support more outsiders engaging with the blocks. Finally limiting numbers of inhabitants and supporting long term residency will ensure that these buildings are cared for. Given the growth of Shanghai and high land values of these sites, it is uncertain how much longer this housing typology will remain. We can only hope that these developers see how other cities, such as Edinburgh, have retained and developed important housing typologies, and support the application of these ideas on a scale suitable to their urban expansion.

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Design to Thrive

A Potentiality Analysis of Vernacular Buildings of Purvanchal towards Contemporary Adaptation

Pranjal Raj Singh[1], Pratibha Patil[2]

[1,2] Department of Architecture and Planning, Visvesvaraya National Institute of Technology, Nagpur, Maharashtra, India.

Abstract: Purvanchal is a geographical and cultural region in the eastern part of Uttar Pradesh in northern India which enjoys a rich cultural heritage with its own architectural style, building techniques and materials. The vernacular houses from the region are built in accordance to the composite climate characterized by extreme summers, cold winters and a humid monsoon season while the cultural, economic and geographical factors act upon it as form modifiers. The approach involved into the design and construction of the vernacular buildings in the region can be further developed and used into contemporary design practices to obtain sustainable results. In this paper, several tangible parameters such as spatial configuration, aesthetic considerations, passive cooling, ventilation techniques, and intangible parameters like lifestyle modifications, functional and cultural aspects, of these Purvanchal houses are taken into consideration for study. A comprehensive review of these vernacular buildings in the unexplored region is carried out in a quest for eminent sustainable, functional and yet climate responsive features with possible application in the architecture of contemporary times. The region long is observing immense ongoing developments since the last decade, making it critical to look for measures in view of a responsible growth. In a nutshell, this study has been able to systematically lay down passive strategies and tools characteristic to the climate of Purvanchal, and in the ongoing trend of distorted and discontinuous architectural practice, the study should provide a driving force to architects and policy makers towards a more directed, sustainable and region specific development.

Keywords: Purvanchal, Climate responsive buildings, passive tools, lifestyle modifications.

Introduction

Architecture has existed even before architects did and a huge section of the society even today build their houses themselves. The vernacular architecture is functional, primitive, local and of domestic nature. The traditional knowledge of this kind of architecture is intuition based and is passed down the generations. Function plays a major role in deciding the form, materials and the construction techniques of these buildings and as these functions get more elaborate with time, modifications are made and continued given the flexibility and user centric nature of the vernacular buildings (King & Amos Rapoport, 1984). The vernacular is not associated with the tradition, the latter being of elite nature and more stringent and sophisticated. The vernacular house grows with the family and is open for additions and subtractions depending upon the requirements of the inhabitants and this flexible nature of the vernacular house make it resource efficient.

Buildings have a huge impact upon the environment given the rapid urbanisation in the developing countries. While the vernacular buildings are climate responsive and need based, the modern buildings replacing them are completely the opposite resulting into a surge in energy demands, lifestyle changes and urban heat island (UHI) effect. Hence, it is very important to look at the vernacular architecture for inspiration, imagery and climate responsive strategies appropriate for a particular context. This would help in bringing down the energy demands and would also conform to the lifestyles of the inhabitants. While the commercial “green” is rigid and irrespective of the context of the building, climate responsive or solar passive buildings are the best way to achieve energy efficiency (A. S. Dili, et al., 2010).

There is an enormous collection of literature available upon vernacular buildings, *Built to Meet Needs* (Oliver, 2006)*, Architecture without Architects* (Rudofsky, 1987) and *Encyclopedia of Vernacular Architecture of the World* (Oliver, 1997) being few of the prominent ones laying down examples of vernacular architecture all around the globe. However, there has been observed lack of documentation and study of vernacular buildings in the geographical region of Purvanchal which has its characterstic architecture style and hence a need was observed to fill this gap through this study. With critical regionalism taking advancement today, the architects of the region should have an idea of what exactly should be understood as vernacular to Purvanchal and only then would they be able to recreate the experience.

Purvanchal: geography and climate

Purvanchal is a geographical region in northern India in eastern part of Uttar Pradesh, surrounded by Nepal on the North, Bihar on the east, Madhya Pradesh on the south and Awadh region on the western side. The region has its characteristic culture, language, geography, climate and architecture with Varanasi, Allahabad and Gorakhpur being the three major cities in the region. The region lies in the planes and is characterised by its extreme climate. Purvanchal experiences cold winters and hot summers and that has been a major challenge for the people of the region.

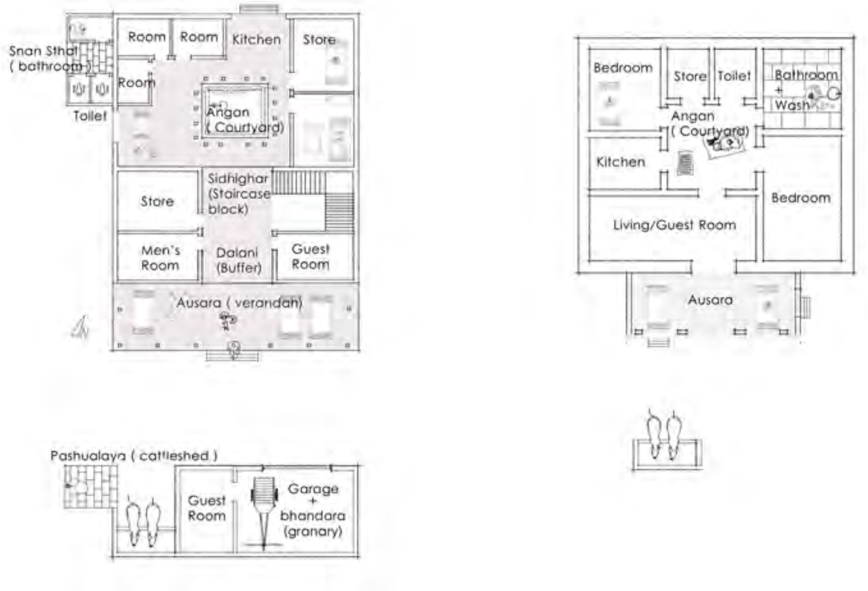
Figure 1 Figure 1: Purvanchal on the map of India

Research Methodology

The research aims at exploring and understanding the usual sustainable practices in the Vernacular buildings of Purvanchal, Uttar Pradesh by selecting, documenting and analysing few case studies from across the vernacular settlements of the region.

Description of selected sample of case study

The selected sample one is a 150 year old building made in mud and lies in the outskirts of Varanasi. The buildings walls are 0.8 to 1m thick made in mud with a clay tile roof on the top supported using a system of Timber and Bamboo girders. As seen in the plan in Figure 2(b) the house has thick external walls with an “Ausarsa” or verandah at the entrance acting as a congregational space for the men. The spaces are small given the thick walls and smaller span with a central courtyard which happens to be the major feature of every vernacular house in the region. The house belonged to a peasant with mediocre level of income.



(a) (b)

Figure 2 Plan of selected samples (a) Masonry house, Campiarganj ;(b) Mud house in Varanasi

The other case study done is a 70 years old masonry house constructed in a small village in Kunwar, Campiarganj (Figure 2(a)). The house is owned by a wealthy farmer family and hence boasts of a larger area with spacious activities. It could be observed that both, the mud and the masonry houses have a similar planning despite being different on the grounds by time, economy, city and material. In the recent past, houses made in brick and concrete were made with the traditional spatial planning and it is only now that it is being completely ignored over westernised house plans. Apart from climate, culture has been identified as a major form determinant for the vernacular buildings (Zare & Kazemian, 2014) and even in Purvanchal, this has been the case.

Traditional knowledge systems and climate mitigation

Traditional knowledge systems are developed as a response to its immediate environment in a way that it resonates with its cultural and traditional beliefs, ethnic values, resident’s desires and needs and the economic and social status of the inhabitants. This bank of wisdom is tried and tested sustaining the ravages of time and has been passed on through generation as a legacy of principles that determine the built response in present context. They play a pivotal role in spatial planning of the dwelling and show precedence over its zoning of activities and spaces.

Table 1. The table describes the activity analysis in relation to the time of the day for the masonry house

Type of space	Nature of space	Time	Activity	Users	Vernacular building practices
(Courtyard)	Private - (Acts as a focal point for multiple household and social activities.)	Morning up to 8 AM Noon from 11AM-3PM Evening 4PM–6PM Night 7PM-onwards	Morning chores like brushing, etc. Washing utensils, drying grains, afternoon nap Socialising and pre-preparation for cooking Washing utensils, sleeping	Everyone Women and children Women and children Women and children	• The courtyard acts as a heat sink in the day time and induces proper pressure differential air circulation. Presence of water source, further aids through evaporative cooling. • It also illuminates the interiors by allowing natural daylight inside.
Kotha (Terrace)	Private –	Noon from 11AM-3PM Night 7PM-onwards	For drying grains, food items, clothes, etc. For sleeping	Everyone Women and children	• The solar radiation falling on the roof's surface is utilized for household chore.
Ausara (verandah)	Semi-private- (Its a link connecting the private household spaces and the outside public areas.)	Morning up to 8 AM Noon from 11AM-3PM Evening 4PM–6PM Night 7PM-onwards	Socializing with neighbours Eating, afternoon nap Socializing, work, playing Sleeping	Everyone Men and kids Men and kids Men and kids	• It acts as a buffer space between the main road and the house which disallows direct sunlight to penetrate inside.
Bhandara (granary)	Semi- private	-	Used for storing grains and other agricultural products, equipment, tools etc.	Mostly men	• It is located away from the main building to disallow contact of moisture and for ease of external access.
Pashualaya (cattle-shed)	Semi- private	-	Utilized for housing cattle	Everyone	• Also, located away from the main building to maintain hygiene, proper comfort conditions for the animals and ease of access.
Dalani (buffer passage)	Semi-private (Utilized as a security feature to put a check on users entering the private zone.		Utilized as guest rooms and/or storage area	Everyone	• Acts as a transition space between the private courtyard zones to the semiprivate living space.

Accordingly, the structure is planned to orient its longer span along the north-south directional axis, in a way that the shortest side faces the southern direction and thus, reduce the direct heat gain due to harsh southern sun. The organization of spaces accommodates different levels of privacy with controlled accessibility and visibility. The interior dwelling spaces are arranged around the courtyard which acts as a focal point for the central organization and is graced by a holi *tulsi* plant in the centre. As air passes through the courtyard into the interior rooms spaces, it carries the sweet fragrance of the incense sticks from the *plant* along and perfumes the entire house. Washroom is placed in the northwest considering the prevailing wind direction so as to exhaust the odour away from the building. Similarly, *swayampak ghar* or kitchen is placed adjacent to the washroom area to ventilate the smoke arising from *chullha* or the stove, outside. Larger fenestrations of the private internal rooms open up into the *angan* (courtyard) and the *ausara* (front yard), against the small punctures that open up into the surrounding to regulate privacy. It also aids in avoiding direct heat gain into the interior spaces.

As agriculture is a major economic activity here, it necessitates the requirement of a granary or *bhandara*. It is detached away from the main dwelling unit to allow ease of external access while not compromising on the residents' privacy. It also checks and disallows the spread of moisture to the granary and helps it to maintain the favoured dry conditions. On the similar lines, the cattle sheds or *pashualaya* is not the part of the main building and is positioned away mainly for maintaining appropriate hygiene conditions and to allow ease of external access to the space without disturbance.

Climate mitigation techniques and approaches

A solar passive design for a dwelling is regulated in such a way that it efficiently uses the incident solar radiation for interior thermal comfort of the users, effectively warming up in the winters and cooling up in the summers along with generating ambient indoor illumination through natural daylight (Jayasudha 2014). Such a design has evolved as a necessity to achieve comfortable living conditions due to inaccessibility to the mechanized means of HVAC. The effectiveness of the climate responsive vernacular practices are explained based on the type of passive design tools and features incorporated and it's planning, the design of building components and related details used in a way to mitigate climatic features.

Courtyards as climate modifiers

Courtyard is a space in the house that is least affected by the annual, seasonal and diurnal weather changes (Figure 3 and 4). Courtyards have been generally referred to as a microclimate modifier in the house due to their ability to moderate high temperatures, channel breezes and adjust the degree of humidity, thus The level of thermal comfort in a courtyard space is determined by the microclimatic forces acting on it, most notably those of radiation and wind.(Das 2006)

Figure 3 and 4. The picture showing daylight penetration the courtyard of mud and masonry house

In case of both the houses, we observe effectively designed courtyards considering the optimum height to width ratio and overhangs are utilized to improve shading and the thick masonry/mud walls promotes thermal lag in the interior space. It has a water stack which keeps the courtyard floor wet and cool, thus, amplifying the cooling effect through the process of evaporative cooling in the interior spaces. Also, the presence of *tulsi* plant helps in achieving the state of thermal comfort further through evapo transpiration measures which also induces moisture in the air.

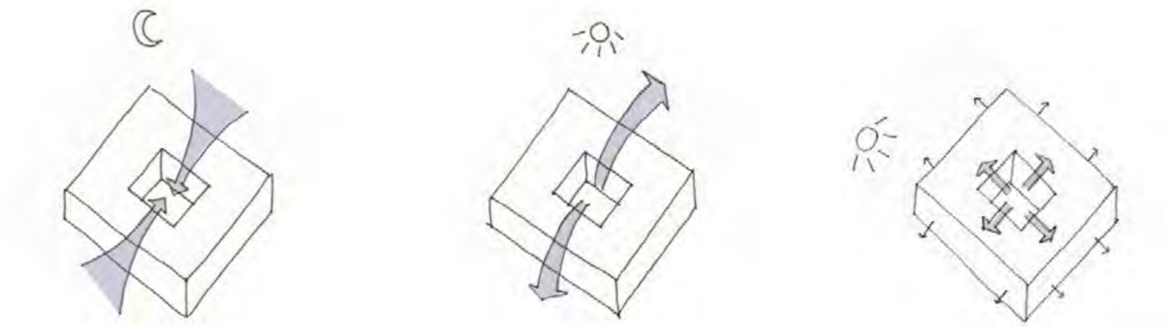


Figure 5: Climatic Implications of Courtyards (Desai, 2011)

Phase 1: Cool night air descends into courtyard and fills surrounding rooms, walls, floors, roofs and ceiling which become cooled and remain so until the late afternoon. Once the sun is up, the courtyard loses heat by radiating it to the sky.

Phase 2: Once the sun strikes the courtyard directly around noon, the cool air starts to rise and leak out of rooms through convection. With the outdoor temperature rising, wall thickness and material prevent heat to penetrate through walls.

Phase 3: In the late afternoon, the courtyard floor and the interior of the house become warmer allowing for convection and heat exchange with the cool interior air.(Figure 5) (Desai, 2011).

Adobe wall as thermal mass

Earth walls have proven to be better thermal insulators as compared to brick or cement concrete block walls (S. Goodhewa, 2005) ; Study performed by Shukla (A. Shukla, 2009) shows that earth has low embodied energy values along with low operational energy and transportation energy values as compared to modern construction materials. A Study

(Mohammed, 2004) further shows the effectiveness of earth in maintaining comfortable indoor thermal environment of houses in relation to outdoor environment.

The mud house is constructed of thick mud walls with the external walls of approximately 1 m width while the internal walls are of 0.8 m width. The walls act as heat absorbers during the day keeping the indoor environment cool and dissipate the heat at night, thereby, achieving thermal comfort through regulating heating and cooling conditions in the interiors. The high specific heat capacity induces such a behaviour which helps in high heat absorption. While adobe walls absorb heat, the courtyards enhance air circulation due differential pressure and temperature conditions; thus, integration of the two helps in achieving optimum thermal comfort conditions in the dwelling. Apart from the effective heat insulation, adobe walls act as effective sound insulators.

Fenestration design

Doors and windows are the only types of fenestrations in the selected case studies and are purposely kept minimum in size and number to disallow direct heat gain from the immediate surroundings (Figure 6 and 7).

The private spaces in the both the case studies have their larger windows opening into the central courtyard and front yard, while the external wall is punctured with small openings (Figure 6,7) for privacy, heat gain and lighting level controls. Apart from this, the above arrangement of fenestration aids in air circulation inside due to the venturi's effect .


Figure 6 and 7. Fenestrations into the walls of the mud house

Roof design

For the mud house, the sloping roof is one of the important climate responsive building components, which aids by reducing incident heat falling on the surface due to its angle of slope (30-35 degree) and reflecting the maximum amount of heat back. The roof height near ridge which is 4 m high, acts as a major insulation space and facilitates a good air flow inside. The roof has punctures to illuminate the interiors with natural daylight and to vent the warm air out of the space through stack effect.

Conclusion

It is observed that despite the extreme weather conditions in the region, the vernacular houses provide comfortable thermal conditions inside the house without being dependent upon any mechanical means for cooling or heating. Apart from the climate responsive design, the houses are built to suit in the culture and lifestyles of the people of Purvanchal. Non tangible and behavioural issues such as privacy and safety are very well addressed by translating it into the planning features such as *dalani* or a buffer space. The modern day architecture of Purvanchal evidently includes flat concrete roofs, closed and decentralised plans, large glass fenestrations and to further counter the adverse impact of these features, mechanised means are used. However these could be easily replaced with sloping clay tile roofing, centralised courtyards and smaller directly exposed openings and buffer spaces. The study reflects upon the possibility for architects to design buildings where people could live with minimal energy consumption just by designing with the primitive and area specific approach of a house and the comfort associated with it. Moreover it is architecture that could help to keep the visual as well as the cultural character of the region alive. While studying a vernacular building, the focus shouldn't be on what is built, but on what has been the process behind the final result. Learning from the folk architects their language of building, would enable the architects of the region to make more responsive architecture, in terms of , an individual, the society, and the environment on the whole .

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Elements of sustainability of the Casbah of Algiers

Fatiha Talmatkadi[1,2]

[1] University Mouloud Mammeri, Department of Architecture, Tizi Ouzou, Algeria, fatihatalmatkadi@yahoo.fr
[2] VUDD Laboratory, Polytechnic School of Architecture and Urbanism (EPAU), Algiers, Algeria, kahinadjiar@yahoo.fr

Abstract: Thanks to the genius of its builders and the ingenuity of its managers, the CASBAH of Algiers has not ceased to fulfill its urban functions, and its economic and social development has not compromised the intergenerational profit for more than 900 years. Today it can be described as an avant-garde model of a sustainable city. The perimeter of the materially predefined city has favored growth by densification in opposition to urban sprawl. The exploitation of the renewable resources necessary for the survival of its inhabitants and its comfort, such as rainwater, sun and winds, have been the subject of systems elaborated with very ingenious rudimentary means combining between the urban structure Adapted from the city and bioclimatic architectural solutions. For the control of nuisances and pollution, a system of functional hierarchization is established, where harmful activities are rejected at the periphery of the city, with relative locations favorable to the neutralization of the pollution generated, and the noblest productions are concealed within the agglomeration. This environmental genius is reinforced by the establishment of a socio-urban system based on spatial hierarchy aimed at preserving cultural values and strengthen its social link between residents, and even social solidarity. This system enables the inhabitants to master and control each other's surroundings, a very effective means of maintaining intimacy, order and security within the neighbourhood unit, while ensuring a community life that is omnipresent at All scales of space. The organization of the city in neighbourhoods gives the autonomous management community, where "Amin" (tribal chief) played the role of intermediary between the population and the Center from Istanbul. A decentralization of power which promotes good governance. This brief reading of the elements that contributed to the sustainability of the Medina of Algiers clearly shows that the approaches related to sustainable development are ultimately only the reaffirmation of ancestral approaches.

Keywords: Casbah of Algiers, sustainable city, bioclimatic architecture, spatial hierarchy, governance.

Introduction

About a thousand years of age, can only testify to the sustainability of this city.

The Casbah of Algiers never ceases to charm artists, fascinate writers and amaze architects and urban planners until today.

"… She is unique. She has no equal. No other has at the same time this orientation, this position, this climate, this precise architecture ... " (Ravereau, 1989)

"... the Casbah gave me the exhilaration to contemplate a mirabilis urbs, a city of miracles testifying to the inexhaustible human capacity to create beauty and grandeur, ..." (Kennedy, 2013)

So many testimonies of great people can only arouse our curiosity to study and understand the peculiarities of this city, and the Indicators of its sustainability.

Sustainability Indicators

Integration with the site

The perfect integration with the site is one of the fundamental elements that has made the exceptional beauty of the city of the Casbah which melt beautifully into the mountains to which it is leaned in the background, At no time the builders of this city wanted to adapt the site to their work, it is rather the work that has adapted to it so respectfully.

The medina of Algiers extends over 45 ha with an average slope varying from 15% to 20%. It is bounded to the north and south by ridge lines, and punctuated by talwegs with slopes of up to 40%, allowing a one-storey shift between two adjacent houses. (Atelier Casbah, 1981)

The slope of the ground is exploited for the construction of shed for animals, independent of the residential function, or subsoil where aeration is ensured by an elevation of the house giving rise to a few intermediate steps between the street and the front door. (Missoum, 2003)

Figure2: Adaptation of constructions to site morphology

A city with a predefined perimeter, a densification factor

The historic city "Medina of Algiers" is naturally delimited by the sea to the east, and the massif of Bouzareah to the west. It is divided into two clearly distinct parts, one, high, residential, and the other, low, commercial and ramparts ensuring its protection against enemies.

The fixed perimeter of the city, did not constrain its growth, nevertheless, it has oriented its development. Instead of spreading out on the surface, once the soil is saturated within the ramparts, the city has developed in height, and it is in this process of densification that resides all the peculiarity of this Medina. In the 17th century we are already witnessing at the creation of the dense city in opposition to urban sprawl.

"... the city is gradually filling up) ... by tightening its road network, ... once the ground is saturated, climb up with an average (GF + 2) template ... We observe a very dense aggregate horizontally that can go as far as a common ownership on four sides of the house in the case of courtyard houses. " (Boughrira-Hadji, 2007)

The densification can spread on the streets, the extensions cover the street by overlapping at different levels in the neighboring houses, the overflowing spaces are called corbels.

Figure 3: Corbelling (for interior surface gains)

Passive comfort / Reduction in energy consumption

The densification

The densification of the city was a key factor in reducing energy consumption. Indeed, urban morphology plays a very important role in the creation of microclimates.

A dense urban fabric preserves the ambient temperatures of the interior spaces, hence the reduction in energy consumption. The device is purely passive, this urban density is obtained from the joining of the constructions to each other, which minimizes the walls in contact with the outside, hence the reduction of the losses of heat during the cold period, And the preservation of sunlight and the creation of shadows during the warm period. More the house is compact less it consumes the energy, the compactness is inversely proportional to the surface of the free walls (C = V / S). (Abdulac, 1982)

The ventilation

The orientation of the city ensures the supply of fresh air through the exploitation of the prevailing summer winds blowing from the northeast side. The capture of these winds is ensured by the implantation of the city perfectly transcribing the topography of the ground. In fact the alignment of the urban facades in parallel with the contour lines causes the movement of the fresh air streams inside the islands. The corbels contribute effectively to the moderation of the temperatures through the creation of the shadows at the level of the public passages. The freshness of the air is also preserved by the presence of public fountains at the level of the streets. As for the prevailing winter winds (north-west), the preservation of the city against these has found its solution both in the elevation of the site, whose massif of Bouzareah makes screen for these winds and reduces significantly their intensity, Than in the orientation of the buildings which give them back.

Figure 4 : Maitrise des vents par la morphologie urbaine

On the architectural plan, all the houses of the Casbah testify to the genius of their builders who were able to develop bioclimatic systems minutely elaborate, having greatly improved the conditions of comfort and well being of their inhabitants.

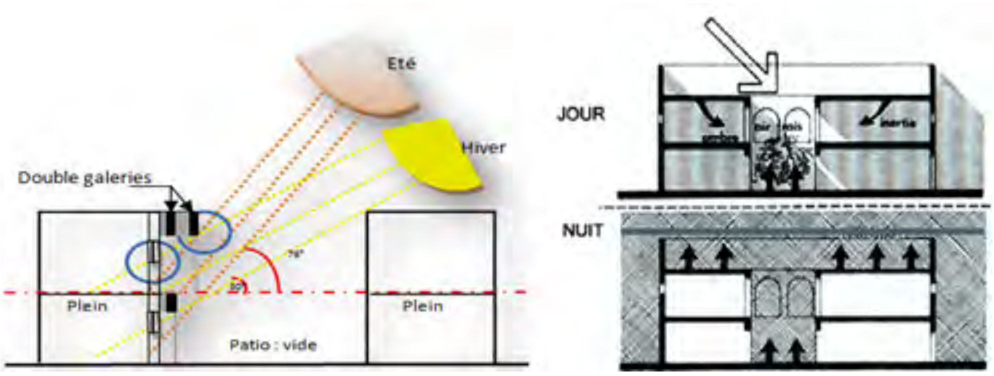

Figure: 5 Galleries and thermal comfort

The houses are equipped with a system of galleries whose depth is consciously reflected accordingly to the trajectory of the solar rays on the horizon line, these constitute a screen blocking their passage in summer , and vice versa in winter. The spaces of the houses most exposed to the sunshine, are sometimes endowed with two rows of gallery, even Dar Aziza and Dar Bakri.

The Comfort is also a matter of handling the stream of air. Indeed most houses have a patio called “wast-al-dar”, which plays the role of thermal regulator, the variation of the temperatures of the air between the inside and the outside creates differences of weight of this one, and this causes its movement. This phenomenon of ventilation is consolidated by another movement caused by the difference in height of the opposite openings in the same space, and the chimney facing the winds of summer (northeast). Moreover, the built-up envelope "... allows the building to benefit from close interior atmospheres Comfort for a wide range of variations in external conditions, without the need for artificial air conditioning.” (Izard, et al, 1979)

Indoor air cooling is also provided by the presence of water fountains at the patio in some houses.

Drinking water supply, use of alternative resources

The builders have adopted an exceptional urban typology, which, coupled with technical methods permitted to exploit rainwater, according to E. Passcuali, “ ... in the upper part of the medina, the houses were built on each side of the depressions of the ground caused by the rainwater runoff. These depressions facilitate the channeling of residual surface water, which initially flows to the surface before being collected by the clay pipes or still brick, and the section of which is proportional to the drained cubic.“ (Missoum, 2003) to end up in the cisterns situated in the basement of the houses.

Addition and distribution is carried out by large-scale installations, transporting water from rivers through aqueducts and underground pipelines, to storage systems (reservoirs, basins, public fountains, etc.). In addition to the rainwater harvesting tanks, public fountains regularly supplied, either by the "saqqaya" water carriers or by piped water pipes, the majority of houses have wells dug into the interior space.

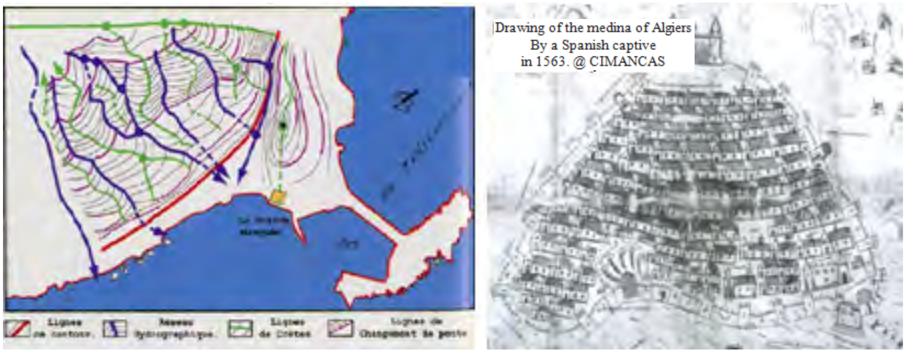

Figure 6: Perfect integration of the constructions with the topography of the site for a better exploitation of the water resources

The city's water supply obeys a set of criteria that fit directly into the sustainable development approach, namely:
Diversity of resources between the drainage of the Wadi water (Wadi M'ghasal and Wadi Knis)(Missoum, 2003), the capture of surface water, artificial water, and recovery of rainwater; Drinking water is a common good. Access is a right for the entire population; Protection of water resources from supply to distribution. Sources of water to the city are well protected (Nicolay, 1989). In order to ensure the regularity of the water supply and not to harm the water rights of others, the diversion of the water is prohibited. The right of penetration into houses for control is thus imposed on the inhabitants (Inalicik, 1986); Use of water as a mechanical energy generator. In 1551, there existed outside the medina, a river used for drinking water and runs the mills (Nicolay, 1989).

Functional organization / Environmental quality

The territory of the city of Algiers combined various functional zones necessary to ensure its autonomy, even residential, commercial, and production zones (industrial) harmoniously articulated with each other. The implantation of these three zones is the result of composition between different constraints linked to three categories of criteria, even social, environmental and economic. Each zone must satisfy a set of requirements:

The topography of the site clearly contributed to the distribution of the zones, since it makes it possible to determine a part with a high level (upper part) and another part with a low slope (lower part), articulated by the street Bab -El-Oued / Bab-Azzoun,.

The residential part must provide comfort (thermal, hygrometric, visual, sound and olfactory), security (health and urban), and privacy (ethical comfort). Indeed, this part occupies the upper part of the city with a well-hierarchized structuring, which keeps it away from nuisances.

For the commercial zone, it has to be in contact with the outside space of the city (attractiveness, accessibility and connectivity), it is therefore located on the lower part of the city facilitating the exchange with other localities and the proximity of the sea allowing Export of products to countries outside the country.

As for the industrial zone, Considered sources of nuisance, industrial activities are located outside Bab-Azzoun, with well-considered sites. The industry requiring a source of motive power for the washing of materials and the evacuation of waste water was located near streams near the sea and on the outskirts of the city to minimize the nuisances (Even the tannery in the ditch near the seashore). Those producing gaseous waste (lime kilns and pottery workshops were installed on the south-west side of the hill (better smoke evacuation by the prevailing winds of the north-west). As for the activities concentrated in the southern part of the medina, between the two walls of the southern gate Bab-Azzoun), a series of mills by the sea, and the quarry on the side of the hill. (Missoum, 2003).

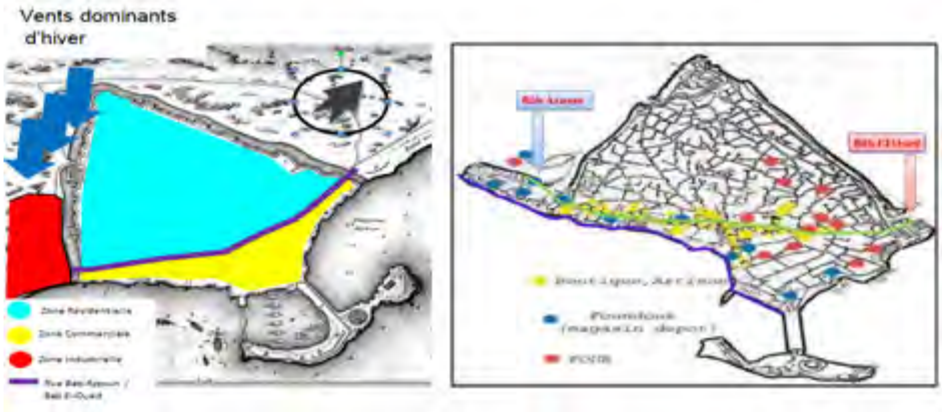

Figure 7: Spatial hierarchy of urban activities

For reasons of food security, during the Berber era, the city was equipped with cultivated areas inside its walls. These surfaces gradually disappeared with the densification of the city, especially in the Ottoman period to make way for houses as urban development progressed (Missoum, 2003).

We are witnessing a form of urban agriculture, a concept that is often referred to contemporary urbanism, which is indeed reflected in its origin at that time. The establishment of businesses in the urban area is subject to technical constraints of servitude. It is regulated by their hierarchy with the religious edifice in relation to criteria of purity. The noble and clean trades such as booksellers, perfumers, tailors are located nearby and the more the craft presents nuisances (sound and olfactory), stand far. As for artisans and traders of consumer products (bread, vegetables ...) are scattered inside the agglomeration. This functional structuring of the city reveals that the environmental concern represented the guiding thread of its urban development, following a well elaborated pattern.

Socio-spatial organization and quality of life

W.Shaler, the American consul, writes, "There is probably no city in the world where there is a more vigilant police force, where fewer legitimate crimes are committed, or where there is better security for people And properties » (Shaler, 1830)

Social values are at the origin of all the human reflection which gave shape to this city, from the urban structure, to the minute architectonic detail. They are governed by the precept "no harm, no foul", known as "la darara wa la dirar", derived from Islamic sharia. The urban and architectural structure of the city combines two contradictory concepts: to separate and to bind, to separate everything that can harm, and to combine everything that can benefit. Hence the functional separation described above in order to preserve the inhabitants from the nuisances that can be induced by public and industrial activities.
Separating foreigners for security and appropriation of space for better management, and separating men and women out of cultural and religious concerns.

The social consolidation of the urban population emerges from its organization in neighborhood units or even neighborhoods known as "houma"

"... the city and its society will evolve towards an organization recognized for the qualities of its urban management, where the neighborhoods, framed and organized, played the role of socialization and integration. " (Ichebouden, 2004)

The neighborhoods developed with subtle gradations of the character of the way. (Raymond, 1989). The road plays the role of filter whose permeability gradually shrinks by a series of interlocking spaces, going from the public space to the private space. It reflects social stratification of the population of the city.
The same logic is projected into the inner space of the introverted house, hierarchized in turn into different levels, driba-skifa-house.

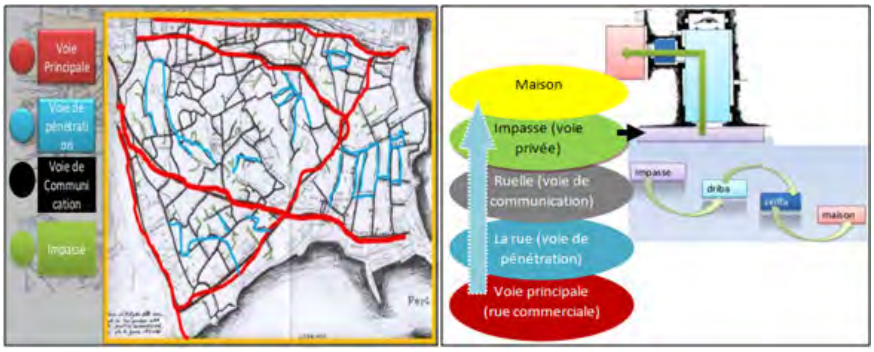

Figure: 8 Spatial hierarchy at the urban and architectural scales

Like the Muslim cities, the districts of the Casbah are the product of a fragmentation of the population into groups (units) whose members are linked according to their type, religious, ethnic or professional affinities (trades). They are constituted around a representative leader "Amin", administrator, whose authority is inversely proportional to that of the central power. (Oumlil, 1982)

The neighborhood organization gives the community autonomy of management, where the "Amin" played the role of relay between the population and the central power emanating from Istanbul (Raymond, 1985). A decentralization of power that promotes good governance.

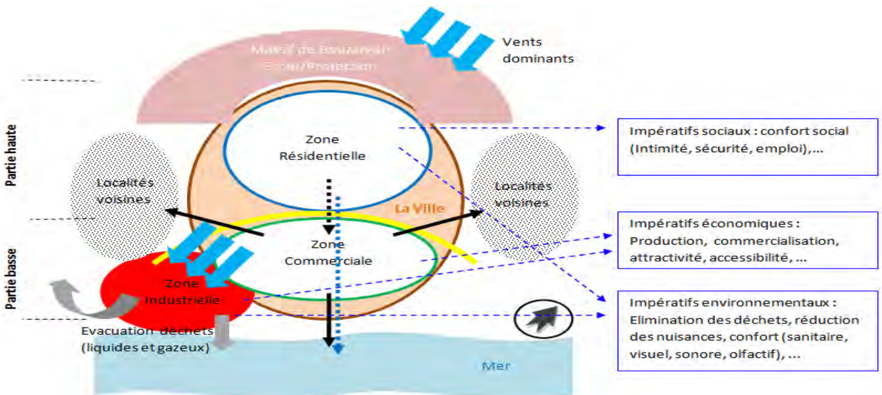

Figure 9: Urban organization as a response to social, economic and environmental imperatives

Conclusion

The medina of Algiers embodies **architecture and sustainable urbanization**, for more than three centuries, this city has not only resisted all the circumstances, but it has also kept a very high socio-economic status. Her qualities make her a timeless city. This city bears witness to a symbiotic combination of men's vital and ethnic needs with environmental factors such as site, climate and materials. It presents a sustainable habitat model implemented through ingenious responses to rudimentary resources. The medina of Algiers offers us a model of architectural and urban evolution whose feedback shows the efficiency and effectiveness for sustainable development, a system that we must seize to reconsider the codes of tomorrow.

Search limits

Given that this article deals with a historical subject and given the lack of studies that have been the subject of statistics on the contribution of the socio-urban model adopted by the Medina of Algiers to sustainable development, this research is based only on the on the historical works relating to the experience of this city during the periods of its sovereignty, even before 1830.

Today quantification cannot be done on the ground seen as the city has changed significantly, especially with the change in the social structure. However, we estimate that, despite the lack of figures, this study has enabled us to detect fairly strong indicators of the sustainability of this city.

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Design to Thrive

The proportion of "*zaguán*" in thermal performance of traditional courtyard houses of Colima City, México

María G. Toris[1], Adolfo Gomez-Amador[1]*, Jorge Ojeda[1]

[1] Faculty of Architecture and Design, University of Colima, Colima, México,
*correspondence email: gmzmdr@gmail.com

Abstract: Achieve passive cooling in buildings is a challenge in tropical climatic regions. Therefore, a naturally ventilated courtyard could be a desirable strategy for a location with hot humid climate like Colima city in México. For this strategy to work properly, the building design composition should enhance appropriate airflow patterns to the courtyard. The *zaguán,* in traditional high mass courtyard houses, is a transitional space that serves as an entry for the house and since its regularly open it enables wind airflow between the street and the courtyard. It is worth mentioning that in this region, transitional spaces have been adapted to its environment so they can function both, as living and circulation spaces and as regulating device for other spaces in the house. For this reason, the *zaguán* could be used as a living space that can induce and control the outdoor airflow into indoor spaces. The aim of this research is to study not only the thermal performance and ventilation conditions in the zaguán as a function of its proportions, but also the influence of this transition space in the immediate spaces of the house. This study first provides a characterization of the *zaguán* in the traditional buildings of Colima including the results of a monitoring carried out in one of the case studies. Then *zaguanes* with different proportions found in the traditional houses of Colima are compared by computer simulation (CFD) with Design Builder® software in order to identify the ones that have better thermal performance and airflow rates. Finally, results are discussed among the different cases.

Keywords: Tropical courtyard, Warm humid climate, Passive cooling, Air flow, Traditional architecture

Introduction

The interest of studying traditional architecture has recently increased not only because it represents a sustainable practice, but also for their values that can be reinterpreted in contemporary architecture. As Traditional architecture is the result of years of adaptation to climate conditions of a specific place, better energy use and better living conditions may be a distinctive aspect of this type of buildings.

The present work is a presentation of an ongoing research that studies the thermal performance of the courtyard houses in a warm humid climate such as Colima, Mexico. Furthermore than characterize thermal performance of the spaces of this traditional typology, the main concern is to study on detail the performance of a specific transitional space in the house, the *zaguán.*

Traditional courtyard house

Situated among different geographic locations and moments in time, courtyard houses are a model of traditional dwelling adapted to cultures and territories. In the case of Colima, traditional courtyard houses have influence of Spanish culture combined with the local one. Its characteristics mainly correspond to a bioclimatic suitability to the environmental conditions of a place that is exposed to elevated temperatures and relative humidity (Elías López & Gómez Amador, 2015). These houses applied a series of bioclimatic strategies to minimize overheating conditions like massive adobe walls, courtyard as microclimatic space, high ceilings and transitional spaces as regulating devices.

In addition to these strategies, to prevent heat gain traditional houses have shown an adaptation that allowed a greater contact with the outside and enhance natural ventilation, a desirable technique for cooling in warm humid climates. For instance, natural ventilation can be used not only to prevent and remove heat gains in the building, but also to promote comfort in its habitants (Givoni, 1994, 1998; Auliciems & Szokolay, 1997)

Furthermore, transitional spaces may have a significant role in courtyard houses as they can regulate the exchanges with the exterior and positively influence people's perceptions of environmental comfort in architecture (Helena Coch, 2003). Additionally, in Colima they have adapted to function also as living spaces that bring a wider variety of climatic conditions into the house (Elías López, 2003).

The zaguán

The *zaguán* is a covered transitional space that serves as an entry for the house and connects the street with the courtyard (RAE, 2015). This space is a horizontal axe for the house and has two main openings, the first one, of smaller dimensions and immediate to the street, its regularly opened and the second one its protect by a gate that allows views and airflows to the courtyard. Even though this space may seem only for circulation and to control privacy but also other sort of activities have taken place there.

According to Rajapaksha et al (2002), the efficiency of a courtyard as a passive cooling strategy is related to the composition of the building in providing appropriate airflow pattern to the courtyard. In this case, horizontal axes play a significant role as they interact with the outdoor and promote air supply to courtyard while ventilating living spaces. The low-pressure zone above the courtyard, where some of the air movement is discharged, induces this wind pattern (Rajapaksha et al, 2001).

Therefore, it may be suggested that *zaguanes* have great importance because depending on its location and configuration they could drive the wind for them or through them to improve its own environmental conditions or have influence in the ventilation patterns of the house.

To determine the importance of this transitional space, the aim of this research is to study the thermal performance and ventilation conditions in the *zaguán* as a consequence of its proportions, as well as its influence in the immediate spaces of the building.

In order to characterize this architectural element on the traditional construction of Colima a random sample was carried out in the central core of the Historic City Centre. *Zaguanes* of twenty-seven traditional houses were registered to establish their representative and variable characteristics that could influence airflows and thermal performance. Characteristics such as disposition inside the house, orientation of the façade, openings areas and ratio between them, construction materials and proportions were taken into consideration as important design parameters. From all of them, proportion was chosen to be the main variable and object of this research.

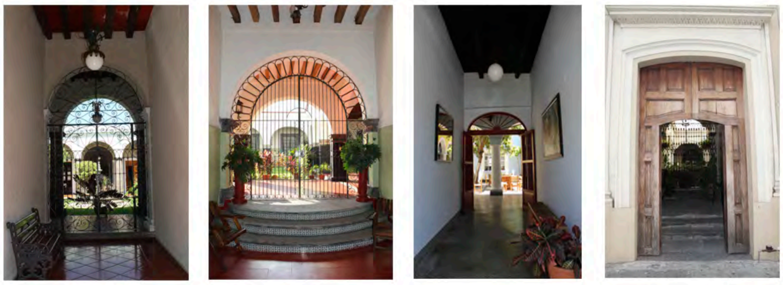

Figure 1. *Zaguanes* from traditional courtyard houses of Colima, México.

Ambient climate

The buildings investigated in this study are in the downtown of Colima, Mexico, at 14’ 37’’ N latitude and about 500 m above sea level. Elevated temperatures and relatively high levels of humidity define the ambient climate. The annual mean temperature is 25 °C. While the month with lower temperatures is January with a mean temperature of 23°C, the months with higher temperatures are May, June and July with means of 27°C. For this work/study, the month of May present the critical conditions with higher temperatures of 35°C and minimum temperatures of 19°C

Field investigation

A case study of a representative courtyard traditional house of Colima was selected to make a field investigation. The 560-square meter rectangular building form is a single storey dwelling that has an almost central rectangular courtyard measuring 9.4 and 10.45 m. Some of the characteristics of this dwelling are a façade oriented to Southwest, a *zaguán* with proportions of 2m width, 6.4m long and 3.88m height. The ratio between its openings areas is 1.24, with the smaller area of the opening immediate to the street (3.6 m^2). The construction systems consist of high mass adobe walls and ceramic roofs.

Data collection

The courtyard building was monitored for 7 days from 12 May to 19 May 2016 where *zaguán* remained opened from 9:00 to 20:00 hours. Air temperature and radiant temperature measurements were taken at 1-hour intervals using datalogger sensors, which recorded day and night. Also, meteorological conditions were recorded each hour at a weather station built on the site using temperature and humidity sensors.

Additionally, wind velocities were recorded along the longitudinal axis of the *zaguán* in one of the days during three periods of 25 minutes at 8:00, 14:00 and 19:00 hrs. Measurements were taken at 1-second interval making a total of 1500 samples which were averaged for a further analysis.

Instrumentation

For air temperature measurements, we use datalogger U12-012 sensors. The accuracy was stated as ± 0.35°C from 0–50°C. Instead of radiant temperature, black globe temperature was measured using a black sphere of .10m on an H08-004-02 Datalogger. The accuracy of this instrument is ± 0.4°C from a range of -20° to 70°C.

For indoor air velocity measurements, we use omnidirectional hot-wire anemometers with dataloggers Delta Ohm model HD2103.2. These have a measuring range from 0.0 to 40 m/s and accuracy of ± 0.2 %.

Measurement locations

Temperature measurements were recorded in the courtyard and in selected indoor and transitional spaces of the building (refer Fig.2). Indoor spaces were measured for air temperature and black globe temperature at their volumetric centre. Wind velocity measurements were recorded at 1.1 m heights at each space along a longitudinal axis that went from the street to the courtyard and going by the *zaguán* the location of the sensors can be appreciated in Fig. 2. As for, outside weather conditions sensors were installed on the site at a 3 m level from the rooftop house ensuring freeness from wind and solar obstructions.

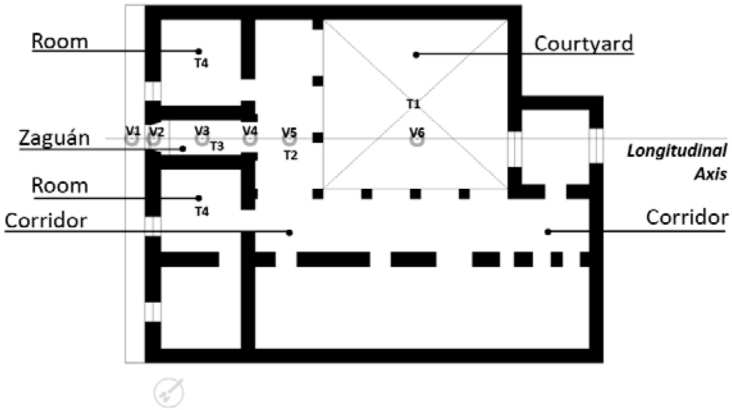

Figure 2. Courtyard house used as case study and measurement locations.

Results of thermal and ventilation measurements

The assessment of measurements is mainly concerned with comparing the *zaguán* thermal performance and wind velocities with other spaces of the house. Regarding dry bulb temperature measurements, the rooms had the lowest temperature swing compared with the exterior temperature. The interior maximum temperature of the rooms was 6 K less than the exterior maximum temperature, with a thermal delay between 3 and 4 hours. The *zaguán* interior maximum temperature was 2.3 K less than the outdoors maximum temperature. And by comparing the corridor and the "zaguán", both transitional spaces, similar thermal performances were observed. Nevertheless, the zaguán had lower temperatures by 0.34 K when the higher temperatures were presented outdoors. The temperature profiles along the day can be appreciated in Figure 3.

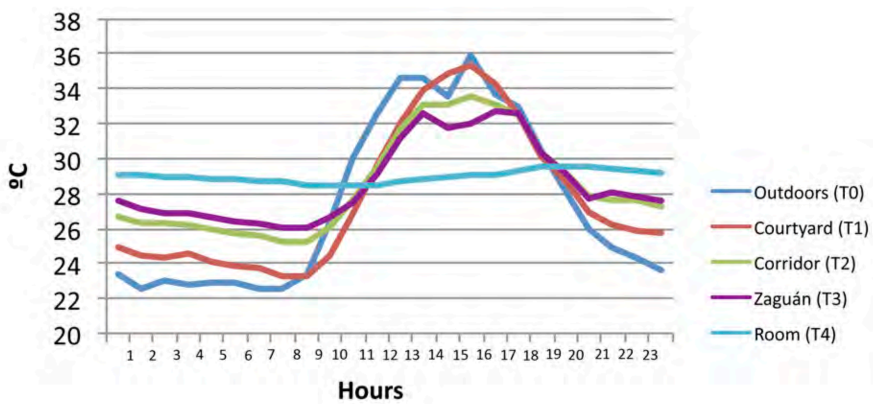

Figure 3. Dry bulb temperatures comparison between different spaces of the house in a representative day

As for wind velocity, the average wind speeds measured on the longitudinal axis were compared. The results show higher wind speeds in the street (V1) than in the courtyard (V6) and in most cases the higher wind speeds were recorded during the period of 14:00 hrs. Among the measurement points inside the dwelling, the opening near the street (V2) had the highest wind velocities. Followed by the points located in the corridor (V5) and in the opening near this one (V4), where there was a slight increase of the speeds in comparison with the centre of the *zaguán* (V3) (refer Table 1). In addition, the wind direction from the street to the courtyard was identified as prevailing.

Table 1. Wind velocities in three periods of time.

		Street (V1)	Opening (V2)	Zaguán (V3)	Opening (V4)	Corridor (V5)	Courtyard (V6)
8.00.00	MAX	3.54	1.85	1.29	1.23	1.36	0.89
	MIN	0.15	0	0	0.02	0	0.01
	MEAN	1.01	0.35	0.29	0.35	0.30	0.22
14.00.00	MAX	7.05	5.62	3.42	3.28	3.7	1.49
	MIN	0.08	0.04	0.07	0.06	0.06	0.06
	MEAN	1.57	1.52	0.92	0.94	1.04	0.41
19.00.00	MAX	5.64	3.61	2.97	2.44	2.49	1.43
	MIN	0.19	0.06	0.05	0.06	0.03	0.05
	MEAN	1.81	0.92	0.61	0.72	0.60	0.40

The field investigation of the case study showed the importance of the building fabric to prevent solar heat gain and that the use ventilation as a strategy to remove heat gain may only be applied between 19:00 – 8:00 hrs., when the exterior temperature its lower than inside one. On the other hand, in these houses transitional spaces bring different thermal and ventilation conditions so that the inhabitants could use them as living spaces depending on the daytime and season. For example, in the *zaguán* “zaguán” an average air velocity of .92 m/s was recorded during 14:00 hrs. that could extend the upper limits of comfort dry bulb temperatures by 3.49°C under temperatures of 32°C in warm humid weather conditions (Auliciems & Szokolay, 2007).

Proportion comparison

In order to perform the thermal evaluation of the *zaguán* with different proportions under the same conditions, Energy Plus simulation program and Design Builder® as an interface were used to get graphic and numerical results approximated to reality. The simulation parameters were obtained from the previous characterization and meteorological-data from the nearest weather station of National Water Commission (CONAGUA) for the month of May 2016.

Results

To evaluate and validate the simulation program as an acceptable tool a previous simulation was carried out using the measurements of the representative case study house. When comparing the simulation results and the field measurements a significant correlation was found. The dry bulb temperatures average in the *zaguán* in both cases showed a difference between them of 0.22 K.

In addition the CFD (computational fluid dynamics) simulation for the wind velocity was carried out. As it can be appreciated in Figure 4, the air velocity flows from the *zaguán* to the corridor, at the outlet of the corridor, the velocity profile shows a parabolic shape, this is due to the friction of the fluid flow with the walls of the zaguán. In certain conditions, this behaviour represents the fully developed flow of the fluid along the zaguán.

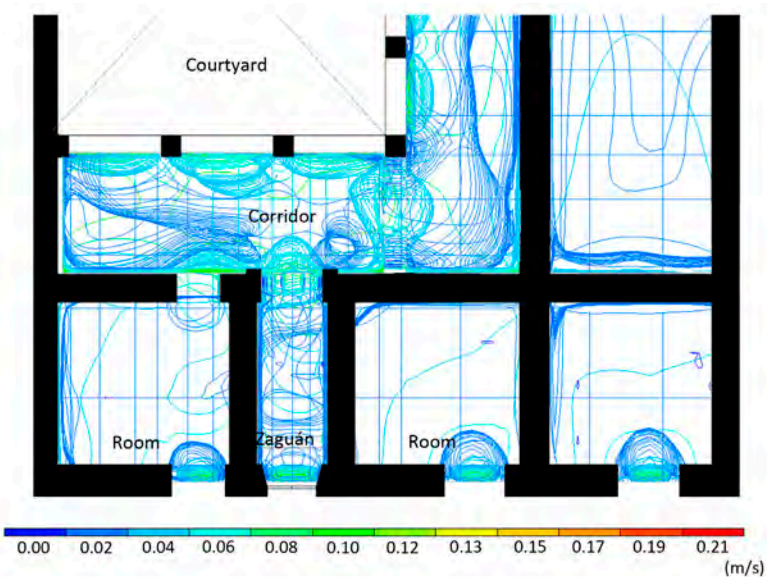

Figure 4. Velocity profiles. CFD simulation results in representative courtyard house.

Analysis unit

Once the simulation program was validated an analysis unit was proposed to make the variations concerning the *zaguán* proportions. The purpose of this analysis unit was to make a simplification of a traditional courtyard house so that it would facilitate the analysis and allow greater control of the variables. The component spaces of this unit were the *zaguán*, the immediate corridor and rooms, as well as the courtyard. All of them spaces that we were interested in studying. To establish he analysis unit characteristics, the previous data of the *zaguán* random sample and the characterization data of the representative house were taken into consideration. This in addition to information of previous investigations of traditional courtyard houses of Colima City that have been carried out.

The proposed analysis unit was a 243-square meter rectangular building with a rectangular courtyard measuring an area of 91 square meters. The building façade was oriented to Southwest, the proportions of the *zaguán* "zaguán" were 2.6m width, 5.9m long and 4.55m height. These proportions are the result of the mean range of values obtained from the random sampling. Also, on both sides of the building adiabatic blocks were placed to avoid heat losses or gains (refer Fig.5).

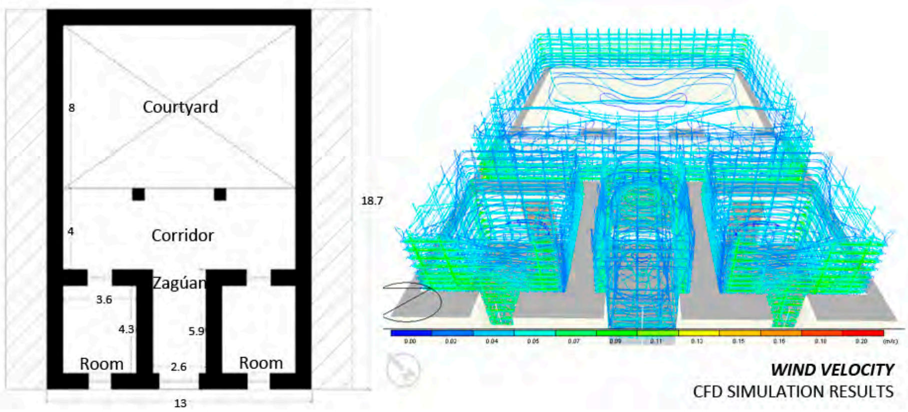

Figure 5. Analysis unit floor plan and results from the CFD simulation

Height comparison

The heights registered in the zaguán of the Colima´s traditional houses went from 3.8m to 5.3m. The lowest dimension (Case 1), the highest dimension (Case 3) and the dimension of the unit analysis (Case 2) were used to model the three cases to compare. In this comparison, every other parameter except from the building height that conditions the zaguán height remains constant.

The assessment of measurements in this stage is mainly concerned with the effectiveness of the zaguán proportions in lowering the air temperatures of its own and surrounding indoor spaces below the level of daytime ambient temperature. As well as to achieve maximum air flow and wind velocities.

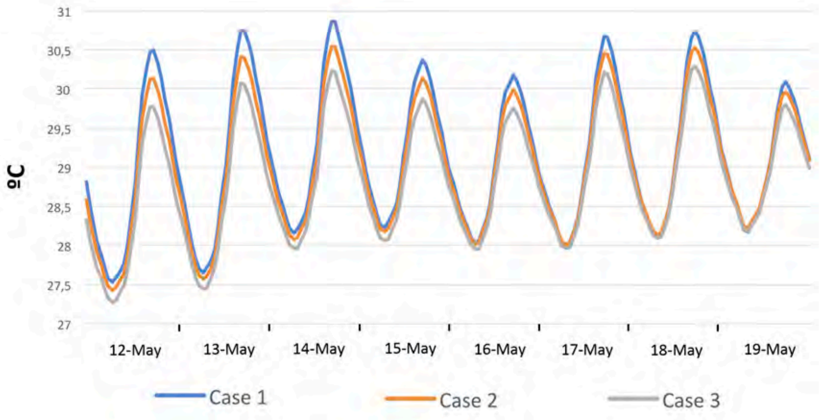

Figure 6. Dry bulb temperature comparison between the three different cases of height.

The simulations carried out for the period of the 12 to 19 of May 2016, showed a difference of 0.57 K in the maximum air day temperature of the *zaguán* between the cases of lower and higher dimensions' height. Case 1 that was the one with lower height presented the higher temperatures. Moreover, the radiant temperature of the *zaguán* with higher dimensions was 0.79 K less than the case with lower dimensions (refer Fig.6).

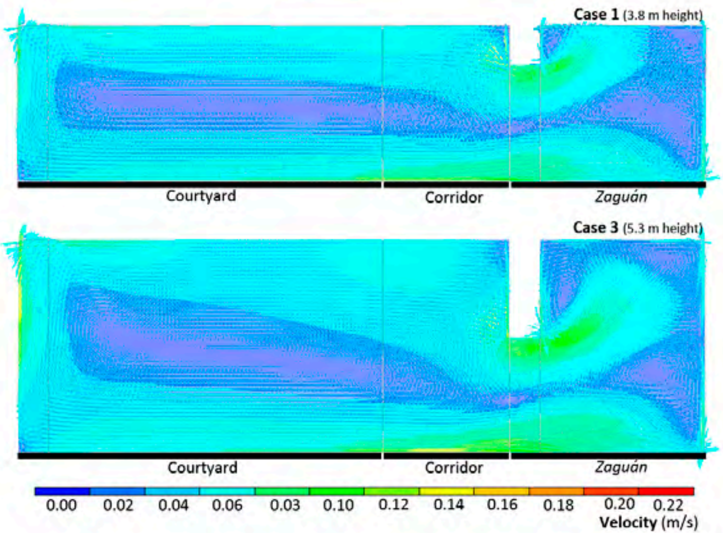

Figure 7. CFD Results. Comparison of velocity vectors between cases of lower and higher height dimension cases with the annual average speeds. Longitudinal slide.

Temperatures of the three models were very closed but by comparing wind velocities results in the *zaguán* greater differences were observed. For example, case 1 (3.8m height) showed an average wind speed of 0.60 m/s and a maximum of 2.08 m/s. Case 2 (4.55 m height) showed an average wind speed of 0.67 m/s and a maximum of 4.44 m/s. Finally, Case 3 (5.33 m height) showed an average wind speed of 0.75 m/s and a maximum of 5.8 m/s (refer Fig. 7).

Comparing the air temperatures in the immediate rooms, the simulation for the zaguán, showed a difference of 0.54 K in the maximum air temperature of the day between the cases of lower and higher dimensions' height. Case 1 that was the one with lower height presented the higher temperature.

Conclusions

Until now only the heights have been compared and these partial results suggest that the changes in the proportions concerning height may not have a major influence on the air temperature of this space. However, greater differences on wind speeds have been observed by modifying the proportions. This brings up the question of whether the *zaguán* may have a greater influence by extending the upper limits of comfort in the inhabitants by increasing wind speeds.

The simulations on this research were realized as if the *zaguán* remain opened during day and night. Which leads us to think that different results may have been obtained if this space remained opened when the exterior temperatures were lower and closed when these were higher. This possibility of control the openings emphasize the importance of *zaguán* as a space in which inhabitants could interact and modify their environment.

Although further simulations and analysis may be need to evaluate the effect of the proportions of this space on the thermal performance and ventilation, we can assume that the importance of this space as a result of its unique conditions. It is reasonable to think that if this element of architecture that have transcended through time, adapted to specific climate conditions and remained in use is a consequence of its important value. Therefore, it may deserve a detailed and deep study that allows us to reuse them according to the characteristics and way of life of the present.

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Design to Thrive

Floating Houses: A design for flood resilience innovations in Bangladesh

Shimantika Bhattacharjee[1], Nandan Mukherjee[2]

[1] Division of Industrialized and Sustainable Construction, Luleå University of Technology, Luleå, Sweden, shimantika.bhattacharjee@ltu.se

[2]Centre for Environmental Change and Human Resilience (CECHR), University of Dundee, Dundee, UK, n.mukherjee@dundee.ac.uk

Abstract: People living in the coastal regions of Bangladesh suffer extremely due to floods. Every year 20% of the land mass (~27,000 km^2) and 30 million inhabitants are exposed to flooding that triggers casualties, infrastructural damage, and deprived access to basic needs. Many policies and strategies already exist for managing flood-related disasters. Flood-shelters save lives but rarely equipped with sufficient food, clean water, sanitation, and electricity. New strategies are required to provide resilience in flood prone areas. This conceptual paper presents an innovative and integrated approach for up-scaling and enhancement of resilience in the flood prone regions of Bangladesh. The paper shows a conceptual design for a floating house with six innovation techniques for self-sufficiency and durability. The techniques include wind and flood tolerant structure, vertical gardening, rainwater harvesting, poultry and bio-digester unit, cage fishing, and renewable energy implementation. The techniques are low-tech and cost-efficient. Use of locally available materials enhances the resilience before and after flood. The design presents equality, balance and immense opportunities for the inhabitants. The 3R strategy (reduce, reuse and recycle) is one of the fundamental concepts of this floating house design. The design explores the possibilities of food security, waste management and energy challenge.

Keywords: Flood, resilience, up-scaling, environmental, water

Introduction

Hydrological occurrence like flood is a common phenomenon in Bangladesh as it is situated on the Ganges Delta and having distributaries that flows into the Bay of Bengal (Islam et al., 2010). The country is affected by flood almost every year and causing damage to people's lives, crops, infrastructure and economy. One of the prominent reason behind such hazards is abrupt changes in climate that contributes in sea level rising and therefore results in flood occurrences (Mimura, 2013). Numerous initiatives were taken into consideration to manage flood related disasters in Bangladesh which includes structural engineering projects such as embankments, raised platform and other temporary shelters (e.g. National Water Policy, National Strategy for Disaster Management, Bangladesh Climate Change Strategy and Action Plan). As a matter of fact this initiatives often results in water logging and restrict sediment flow, reducing agricultural productivity and also generates social vulnerability. The objectives of such projects are deprived of a systematic and integrated approach and are not optimized for long term considerations. The systematic and complex nature of resilience and the interdependence between environmental hazards and social, economic and welfare need of people is often ignored while managing the flood related disasters. This lead to a devastated effect on people's life during pre and post phase of flood.

Climate change is enhancing intensity, frequency of floods which then exacerbate many other challenges, including livelihoods, poverty and gender relations in interrelated ways (Tanner, et al., 2007). The interrelated ways of flood impact is elaborated in Table 1.

Table 1: Integrated nature of flood impacts in Bangladesh

Flood Impact	**Explanation**
Loss of livelihood	People cannot continue income generation activities (e.g. agricultural production, labor) during/after floods. Coping involves relying on micro-credit & emergency aid which increases debt and poverty.
Poor health and mortality	Mortality from flood occurs from drowning, snake bites, and malnutrition. Poor health delays recovery and death can result in family members falling into extreme poverty.
Deprived access to water and sanitation	Permanent water supply and sanitation points become inundated. The temporary source of potable water is insufficient and of inadequate quality. Open defecation and poor waste management can pollute water. Restoration of water supplies and sanitation points is expensive, increasing the burden both on the households & public entities.
Food and nutrition	Food and nutrition security during and after floods is affected through loss of agricultural production and livelihoods and high reliance on emergency support/aid. Food insecurity causes mortality or ill health, limiting recovery.
Lack of safe places during floods	Temporary migration to flood shelters is key for poor households. However, shelters do not accommodate most people. Children and women can experience abuse and rape. This, combined with limited essential support services during floods (partly because of theft of supplies) affects willingness to use shelters.
Loss of education	Loss of school days is common (e.g. when schools are used as shelters or when they cannot access schools). It can lead to permanent dropout.
Damage to infrastructure	Restoring transportation, communication, & other infrastructures increases the nation's economic burden and limits spending on other crucial needs (e.g. health, poverty alleviation, water supply, sanitation).

Therefore, the study creates an urge to take a sustainable, integrated and longer-term approach that simultaneously enhances generalized resilience (e.g. livelihood and poverty related challenges) while also enhancing resilience specific to flooding. This study emphasizes on developing a conceptual model of designing a floating house integrating six innovation techniques for flood prone areas in Bangladesh. It conceptualizes the idea of floating houses functioning both on land and water. Similar examples on amphibious houses were found in Europe and in the USA situated in two different climate zones (English, 2009). Another study showed a similar design consideration for the urban poor during the crisis of flood (Prosun, 2011) . Moreover, implementation of flood resilient house practices and inclusion of the new guidelines for buildings situated in the flood prone areas in Bangladesh is necessary.

Figure 1 shows the inundated areas during flood events in 1974, 1988 and 1998. It can be seen that the percentage of total area inundated was approximately 35% in 1974, which increased to around 49% by 1998.

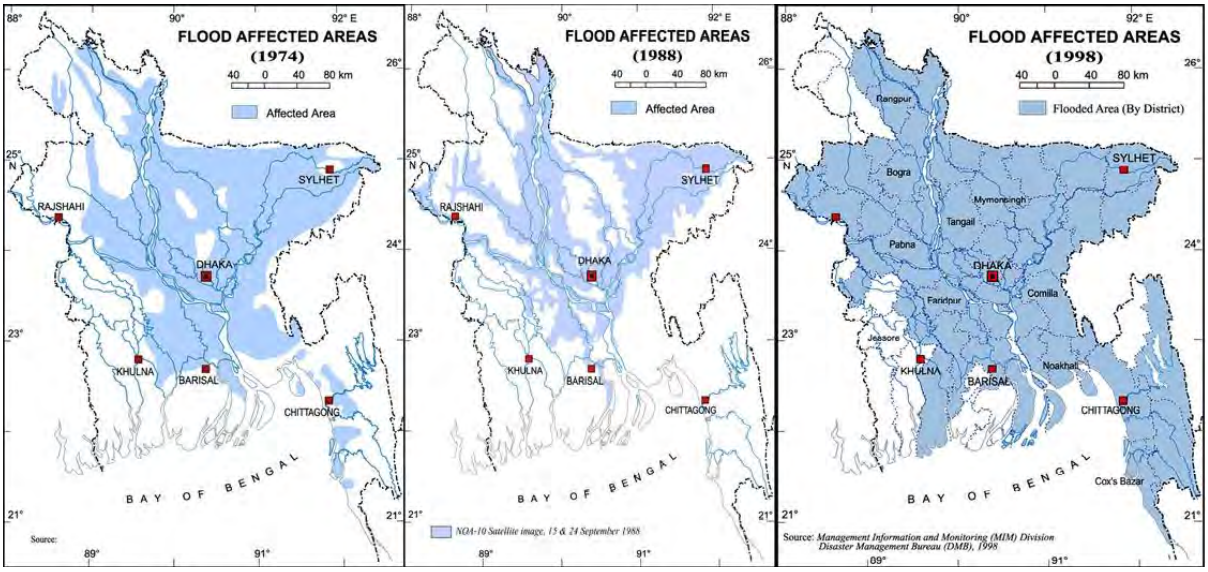

Figure 1. Flood affected areas in the map of Bangladesh (Agrawala et al., 2003)

Aims and Objectives

The aim of this study is to develop an innovative and sustainable floating house design which is environment friendly and can be built using locally available materials. The concept is to design a house to cope with flood and corresponding water related disasters. The floating house is conceptualized on “passive house techniques” that can be adapted and optimized towards local climate condition. The above context provides necessary ground for a permanent static elevation in the form of residential structures to avoid forced displacement of human population during flood. The target is to evaluate energy-efficient innovation strategies to enhance the resilience of households and communities to before, during and after flooding. Specific objectives are given below:

1. Mitigation of climate change induced loss and damage.
2. Implementation of reduce, reuse and recyclable potential in the floating house design.
3. Self-economic hub for livelihood support and income generation through food production.
4. Exploration of critical resilience dimensions and ensure safety and security of the flood affected people.
5. Replacement of non-renewable sources by renewable sources for energy production.
6. Energy-efficient design aspects and passive strategies to reduce the environmental burden and GHG emission.

Approach and methods

A conceptual floating house model

The goal of this study is to test the floating house concept in a real environment. Therefore, monsoon flood-prone areas of Southern Bangladesh were selected. The locations are Char Bhaga, Sakhipur, and Tarabunia in the Bhedarganj upazilla at the Shariatpur District. The locations were chosen based on the following considerations: (a) are highly exposed to monsoonal flooding; (b) are readily accessible; (c) face complex issues relating to vulnerability.

The idea of a floating house has been conceptualized to address the climate change issues. The design is a self-sufficient floating house which emerge as a source of basic needs during the crisis period as shown in Figure 2. The idea of a “floating house” is formulated based on the concept of a tree. The physiological and psychological attributes of a tree has been considered thoroughly while conceptualizing the idea of a floating house. It is considered to be a self-sufficient house with the ability to producing food through vertical vegetation even in the period of flood. This floating house can serve as a potential shelter for the victims of flood prioritized to improve their condition through safety, security and income generated activities.

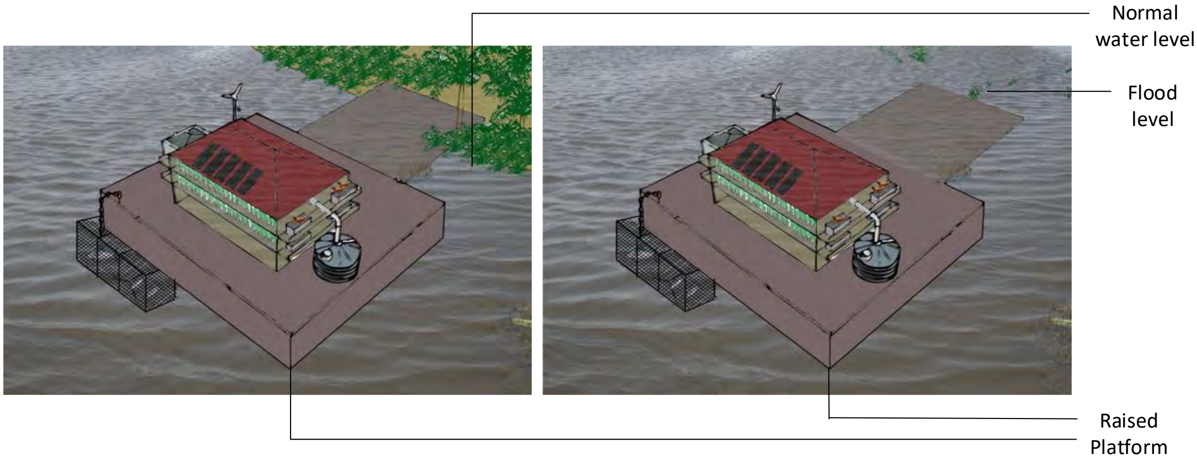

Figure 2. The conceptual 3D floating house model before and during flood

The project is highly innovative for three reasons. First, the idea of a floating resilient house that integrates multiple other innovations (Figure 2, Table 2) to provide renewable energy; income generation; food production before, during and after floods; and security is entirely new. Second, a participatory approach can be included so that it can it provide learning methods and developmental evaluation to encourage innovation of community members in the project. Third, the design of the up-scaling strategy is also highly innovative in the way it draws on extensive local insights gained through collaborative learning approaches that will help understand both the effectiveness of the resilience innovations and of the participatory process used to develop and implement them.

The study will also add significant new knowledge about resilience, including about: (1) the systemic nature of resilience, including relationship between diverse challenges facing local people; (2) integrated approaches and innovations to enhance resilience; (3) designing upscaling strategies for resilience; and (4) new ‘know how’ knowledge about implementing resilience through inclusive and participatory approaches, including the challenges and opportunities of doing so.

Innovation in the floating house concept

The aim of this floating house is to with-stand the current and future climate change impact and simultaneously contribute to reduction in GHG emission through environment friendly technological interventions. Due to the adverse impact of climate change it is therefore evident to build houses sustainably. Passive strategies such as implementation of renewable technology have been introduced to address the climate change issues. A few innovation techniques have been integrated with the floating house concept which is described below precisely (Nayar, et al., 1989) (Brugere, et al., 2001) in Table 2.

Table 2: Specific innovations to be integrated into flood resilient houses

Innovation	Explanation	Evidence for applicability
Wind tolerant floating houses	A floating house built using local materials to be resilient to floods and wind. This addresses problems of temporary displacement to shelter, inadequate space, abuse and assault of children	There has been demonstration regarding Cyclone Proof Houses in Bangladesh designed by architecture dept. of Brac university. House Building Research Institute in Bnagladesh also developed a floating house built with locally available materials (Ferro Cement Floating House (https://goo.gl/Sm7rWJ). Engineers at the University of Alabama, Birmingham are using similar concepts (https://goo.gl/NYX26T) and the Asian Disaster Preparedness
Vertical gardening/ hydroponics	Walls pf floating houses for vertical gardening using hydroponics to enhance food security and income.	Accommodating agriculture as economic activity in a limited space and during the time of emergency is critical. Extensive research has shown that hydroponically grown crops yield 20% more produce than conventional farming techniques.
Rainwater harvesting	Underground and overhead tanks to store rainwater provide safe water supplies	Rainwater is the safest drinking water option during the flood and the potential for rainwater harvesting is widely researched. BRAC and NGO forum have implemented such options in Bangladesh (https://goo.gl/xk8fRj)
Poultry and Biodigester unit	Biodigesters produce power from household & poultry waste, with residue used as fish feed & fertilizer.	The feasibility of bio-digesters has been widely tested in Bangladesh. IDCOL, a Government-supported NGO in Bangladesh has already implemented thousands of such low-cost demonstrations in Bangladesh (https://goo.gl/EfODgG).
Cage fishing	A fishing unit using aquaponics provides protein and income.	This complements vertical agriculture and has been researched extensively (e.g. Brouwer et al, 2007) and implemented in the 'Fisheries Projects' in Bangladesh (https://goo.gl/MxtLeU)
Renewable energy	Small hybrid solar panels/ wind turbines will generate electricity to supplement the biodigester.	The applicability such work has been demonstrated since the 1980's (e.g. Nayar et al,1989). NGOs in Bangladesh, including BRAC, Grameen Bank, IDCOL has already implemented millions of such systems (https://goo.gl/Px2YSa).

The figure below (Figure 3) shows the floating house model integrated with the six innovation techniques summarized in Table 2.

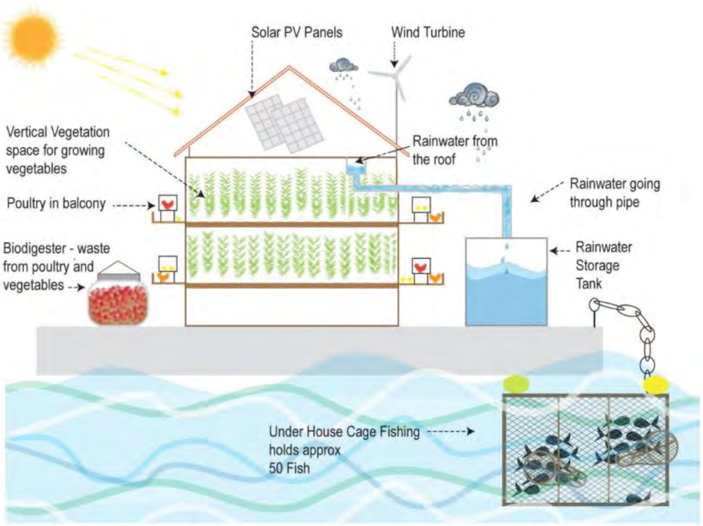

Figure 3. A conceptual diagram illustrating the floating house model integrated with six innovation techniques

According to the concept of amphibious structure the floating house will be designed in such a way that it can elevate upwards during flood and as the water level recedes it will return to the ground level. The water level scenario during pre and post flood condition is shown in figure 4.

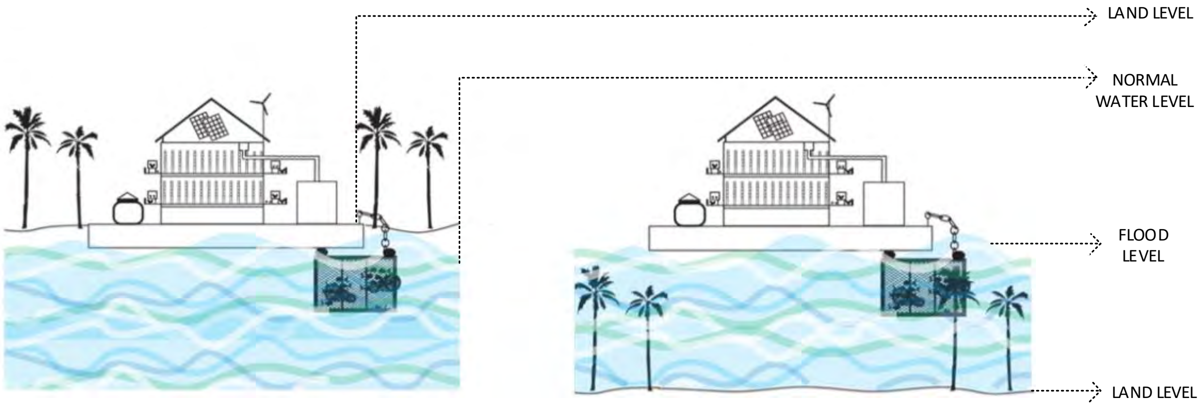

Figure 4. Water level scenario before and during flood

Addressing Objective 1: Mitigation of climate change induced loss and damage

Climate change is an unavoidable environmental phenomenon that induces loss and damage in different dimensions (Pinninti, 2014). There are certain types of efforts for managing loss & damage which has long term environmental or social consequences. Building embankments along the river side to reduce the exposure of the affected population, however, can obstruct the sedimentation in the flood plain which might result in irrecoverable loss to the floodplain dependent ecosystem components and services (Potter, 2013). Simultaneously there are certain conditions or limits to the perceived adaptation and mitigation efforts where nothing could be done, or possible in future. For example, the current level of greenhouse gas concentrations in the atmosphere would let us such situations where some level of warming is certain, no matter how robust is our emission reduction targets or adaptation efforts will be. The floating house concept is an effort and approach towards tackling the water related hazards like flood in a sustainable way and thus contributing towards reducing the greenhouse emissions through different innovation techniques. The longer term goals are: a) r*eduction towards the exposure of water related hazards, b) minimum level of residual impact on the environment, and c) maximizing the potential for complementary or double benefits from adaptation and mitigation.*

Addressing objective 2: Implementation of reduce, reuse and recyclable potential in the floating house design.

The 3R strategy is a sustainable way of managing the waste and the resource value of materials can be fully utilized in the process. The rain water harvesting determines the reuse potential and as can been from figure 3 rain water will be collected in the storage tank and filtered through environment friendly bio-sand filtration. Later this water can be used daily for household and during the emergency situation like flood. It does not only produce gas but also produce fertilizer from the organic household waste and poultry. Gas can be used for household cooking and the fertilizer can be provided as the food for plants and fish. Therefore, the organic wastes are being reused and recycled in the process. The 3R strategy decreases the amount to be disposed and thus contributes to reduction in greenhouse gas emission. The process is low-tech, sustainable and cost-efficient and therefore people can be benefited from adopting such innovation technique.

Addressing objective 3: Self-economic hub for livelihood support and income generation through food production.

The floating house concept has been developed to improve the wellbeing of the inhabitants. As already mentioned that hazards like flood has a disastrous and detrimental impact on economical, physical and psychological condition of the affected people. Supporting the livelihood were prioritized during the formulation of the concept. The house is a source of self-economic hub. Food security can be ensured through production of vertical vegetation, poultry and fish (see figure 3). Moreover, the surplus vegetables, fish and poultry can be sold in the local market and thus serve as a purpose of income generation activity for the inhabitants.

Addressing objective 4: Exploration of critical resilience dimensions and ensure safety and security of the flood affected people

The temporary shelter often fails to provide the basic facilities and services to the affected people. Report shows that such temporary shelter cannot provide proper safety and security towards women and children (Brouwer, et al., 2007). Therefore, instead of a temporary shelter a permanent solution like floating house can alleviate their pains and sorrows.

Addressing objective 5: Replacement of non –renewable sources by renewable sources for energy production

Bangladesh is fully dependent on fossil fuels to generate electricity which are being depleted at an alarming rate. People suffer from electricity shortage extremely which is considered as one of the biggest crisis at present. However, approximately 30% of the total populations are connected to the national electricity grid of Bangladesh (Taheruzzaman et al., 2016). People living in the village areas has access to the rural electrification grid which has very poor performance and frequently suffers from shutting down of electricity. The country has immense opportunities for implementing solar energy (Islam et al., 2014). As being situated in semi–tropical region of south Asia, Bangladesh receives abundant sunlight year round. Scientists with support from local NGO's, rural electrification board and the infrastructure development company have initiated the solar panel implantation plan in the rural areas of Bangladesh (Ahammed &Taufiq, 2008). Using daylight the solar panels installed on the roof can produce electricity and meet the needs of local people (Prasad & Snow, 2014). Apart from solar panels the use of wind turbines have also been considered to generate electricity when there is no sunlight available (Nayar, et al., 1989). The extra electricity produced can be sold to the local electrification board as well. Successful implementation of these passive energy sources can encourage other rural areas to adopt this technology and thus contribute in reducing the environmental burden.

Addressing objective 6: Energy-efficient design aspects and passive strategies to reduce the environmental burden and GHG emission

The floating house is naturally ventilated. It is considered as one of the main techniques for keeping moderate temperatures in buildings specially situated in the hot dry and tropical climates. The natural ventilation can help to improve the indoor air quality through fresh air flow. Integrating the vertical vegetation is another strategy incorporated in this concept to improve the indoor and outdoor environment. Addition of vegetation on the facades will generate lower temperature during warm summer months comparatively than the conventional façades. Both of the above mentioned strategies can reduce the energy consumption and greenhouse gas emission simultaneously.

Conclusion

The approach and collaborative nature of this concept are highly amenable to scaling up and longer term sustainability that would reach around 20,000 households and 1 million people. This concept describes an innovative approach towards adaptation compared to the traditional flood resilient infrastructure. The resilience initiatives have been chosen because of their direct relevance to local needs, affordability, and ability to address multiple challenges facing households. The study also specifically seeks to enhance potential scalability through learning about the effectiveness of innovations, how they can be implemented and by designing scaling approaches. It also includes approaches to implementation that are community led rather than imposed by engineers, planners or researchers. Overall, the combination of attention to appropriate innovations, the process of engagement and inclusivity, designing scalability, and consideration of wider governance and policy issues greatly enhance the potential for sustainability and wider impact.

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Design to Thrive

Environmental Sustainability Evaluation Method in Public Works Audit: Analysis of the Maciço do Morro da Cruz - Florianopolis, SC, Brazil

Alessandra Rodrigues Vieira de Castro[1], Anna Paula Rodrigues[2] and Orlando Vieira de Castro Junior[3]

[1] Faculdade de Arquitetura e Urbanismo, Universidade de Brasília, Brasil, alessandra.rodrigues@cgu.gov.br;
[2] Forestry PhD., University of Canterbury, New Zealand, annapaulabsb@hotmail.com;
[3] Controladoria, Universidade Federal do Ceará, Brasil, orlando.castro-junior@cgu.gov.br

Abstract: In Brazil, the public sector is the largest constructor in the country. However, considerations of the impacts of the conventional constructive techniques adopted and green technologies alternatives hardly take place in the public sector. Audit works carried out by the Federal Government's high internal control body cover public projects and works but for compliance measurements mostly. In addition, these audit works help to improve public policies. Thus, this study is aimed at include environmental sustainability assessment as a subject part of public audit works regarding to urbanization. This research used the case study strategy in a descriptive way in order to apply an analysis model. It lays on a specific thematic clipping: integrated water management under the environmental layer view. The constructed analytical model is based on sustainability indicators. The selected urban fraction is a marginalized area, in an insular city. Public power is carrying out urbanization works in this locality. This research shows the viability to include principles of sustainability assessment in audits works of urbanization. Analyzing the suitability using such principles in public works could enforce best management practices to become an alternative or a complementary part to the conventional public network.

Keywords: Sustainable Urban Planning, Integrated Water Management, Public Works Audit, Sustainability Indicators, Clandestine Human Settlements.

Introduction

The Brazilian government is gradually seeking modernization. Institutions are trying to conform to the principles of good governance and have been adopting instruments of performance analysis and accountability more frequently (Ministério do Planejamento, 2009). Analysis models, indicators and indexes have been developed in the last decades to become management and result evaluation tools (Ministério do Planejamento, 2009). Similarly, control bodies have been incorporating such tools into auditing works on governance, public policies and government expenditure assessments. Such issues must be monitored to guarantee they conform to both the needs of the State and of the community. In addition, the right to a balanced environment is one of the fundamental needs of the Brazilian citizen (Brazil, 1988). The need to use indicators of environmental sustainability arises within this context. An indicator can assess the estate or point in time of a project regarding a specific goal and contribute to the elaboration of plans for improvements (Sustainable Measures, 1999, in Sattler, 2015).

The Brazilian legislation establishes that goods and services acquired by the public authorities must promote sustainable development (Brazil, 1993). It also requires that public works projects should be technically feasible and have adequate environmental treatment. Despite the national legislation requirements, there has been little progress towards achieving sustainable public works (Lima, 2013). The Brazilian government is concerned to provide basic sanitation but the efforts to use more environmentally sustainable solutions are incipient. In Brazil, the Office of the Comptroller General (CGU henceforth) is the Federal Government's high internal control body responsible for conducting public works audits. However, little is discussed about ecological solutions to basic sanitation. Public works audits commonly refer to the conformity with the bidding process, documentary compliance and compatibility between design and implementation in physical, chronological and financial terms.

This study aimed at proposing an auditing method for urbanization works using environmental sustainability indicators and Best Management Practices (Ellis, 2010; Niemczynowicz, 1999) to achieve integrated water management (IWM) techniques. The goal of this study also was to support that, with the aid of environmental indicators (i.e. sustainable urban drainage systems, low-impact urban design and development, water-sensitive urban design, green infrastructure), audit reports can be a tool to enforce a governance leap in the formulation of public policies for the execution of urban works.

Research Method

The case study was selected from a poor community on a hill, called Maciço do Morro da Cruz (MMC henceforth), which is located downtown Florianopolis, a coastal and insular Brazilian city in Santa Catarina State, south of Brazil. Florianopolis has the third highest Municipal Human Development Index (IDHM: 0.847; UNDP, 2010) and one of the highest per capita incomes of Brazil. As such, there are excellent housing options for the portion of citizens who can afford it. However, there are places in the city occupied by poor clandestine land settlements in precarious conditions. These segregated areas are one of the several problems related to accelerated population growth in Florianopolis, which in the last 30 years, has been the result of public policies without proper development strategies and urban planning (Sugai 2015). Currently, there are 18 irregular settlements in MMC, which is a 283-meter-high granite hill (Tomás, 2012; Hübner *et al*., 2004). The local government legally recognized the need to provide urban services to the MMC's inhabitants to reduce social inequality in these precarious settlements (Governo do Estado de Santa Catarina, 2012; Salomé, 2014). Efforts to consolidate this plan have intensified since 2007 (Tomás, 2012; Ministério do Planejamento, 2016), with CGU supervising the urbanization works since 2012 (CGU 2014; CGU, 2016).

The study site selected for this research was a street called Nova Descoberta within Mont Serrat Community, one of the 18 tenements in MMC (Figure 01). Nova Descoberta Street is located in an environmentally vulnerable area, designated as a Limited Use Preservation Area[1] (or APL in Portuguese acronym) by the Brazilian Forest Code.

[1] "sites that due to their geomorphology or vegetation cover characteristics are not able to support certain forms of land use without prejudice to the ecological balance or the natural landscape (Hübner *et al.*, 2004).

Figure 1 Left - Maciço do Morro da Cruz view (red square), in Florianopolis - SC. Right - Monte Serrat community (green square) and Nova Descoberta Street (red polygon). Source: Santa Catarina (2012); Florianopolis (2014) and Salomé (2014).

This research was carried out in a descriptive method based on environmental indicators (Gil, 2008). Given the complexity and breadth of the subject, the scope of the evaluation was limited to the aspects of integrated water management (IWM) to demonstrate the application of the proposed evaluation criteria. Environmental sustainability principles and indicators were identified based on the approach used by Belo Horizonte (Belo Horizonte, 2002 in Bennet, 2004), Florianopolis (CECA, 2001 in Bennet, 2004) and Andrade and Lemos (2015), and separated into five topics: Water Supply; Sewage; Rainwater; Water Source, and Wastewater.

Belo Horizonte (2002 in Bennet, 2004; Sattler, 2015) created a mathematical model to obtain a final index for a planning unit within the municipal territory. CECA (1999 in Bennet, 2004; Sattler, 2015) proposed indicators to measure socio-environmental quality in the city of Florianopolis, considering the specificities of the city, such as its island condition, its geomorphological and environmental characteristics. Finally, Andrade and Lemos (2015) developed environmental indicators based on principles on the quality of urban morphology and green enterprises certification.

Field data was collected from September to November 2016, followed by the analysis of public documents and literature review. The data were later arranged in dichotomous variables (yes or no). Lastly, specific recommendations found in the literature regarding environmental impacts derived from urbanization were selected to assess the situation of the study case.

Results and discussion

Based on the five sustainability indicators regarding aspects of integrated water management (IWM), Table 1 shows the result of the evaluation of the Nova Descoberta Street.

Table 1 - Evaluation of the Nova Descoberta Street with a focus on integrated water management (IWM).

ENVIRONMENTAL INDICATOR OF SUSTAINABILITY	PERFORMANCE			
	NO	NOT APPLICABLE	YES	COMMENTS
1 Water Supply				
1.1 Treated water supply			x	Interviews revealed a 100% of houses have potable water supply.
1.2 Remote water withdrawal			x	About 30 Km from the study site.
1.3 Self-sufficiency	X			This region needs to import water for its livelihood.
2 Sewage				
2.1 Sewer network availability			x	Interviews revealed a 100% of houses are connected to public sewer network
2.2 Decentralized sewage treatment incentive program	X			The water and sanitation company only recommends residents build a sump or sink.
3 Rainwater				
3.1 Natural systems for rainwater retention	X			Techniques used are traditional, so unfiltered water are drained through pipes directed to the local stream.
3.2 Collection and storage of rainwater in public spaces and buildings	X			There are no natural or artificial systems for rainwater retention. There is not rainwater harvesting and storage in public spaces and buildings.
4 Water Source				
4.1 Respect for the natural condition of perennial and intermittent watercourses and recovery of streams	X			The existing stream in the locality was channeled in order flow under the houses. The drainage system leads the rainwater to this stream.
4.2 Respect to topography and streams like boundaries between neighborhoods	X			The design of roads and blocks does not follow the contour lines. The design is not linked to green infrastructures.
5 Waste Water				
5.1 Ecological treatment of wastewater	X			There is no treatment of wastewater.
5.2 Wastewater reuse for non-potable uses	X			There is no wastewater reuse.

For evaluation purposes, the case study was divided in two sectors (Figure 2). In the first sector, the road is flat (between the red and blue arrows, 150 to 140 m) and the street was partially paved with permeable material. The site is steep in sector 2 (between the blue and yellow arrows, 140 to 105 m), and public spaces were completely waterproofed.

Nova Descoberta Street today has a network of water supply, sewage and drainage (Table 1, items 1.1). This represents an upgrade in terms of basic sanitation when it comes to precarious settlements.

However, the project was not conducted in a sustainable manner concerning the hydrological cycle. Serious issues regarding the Florianopolis' water supply system were detected: insufficiency in water supply, the inexistence of a permanent program to protect underground and surface water sources; lack of grants for water abstraction from springs and of an environmental license for the operation of the station; lack of water resource plans for the regional watersheds; inadequate water treatment system; absence of a sanitary permit for the treatment laboratory operation; inaccurate available water volume data; water wastage during transportation or due to clandestine connections (43.31%); inadequate system maintenance; old equipment and water wastage by consumers (TCE/Santa Catarina, 2011).

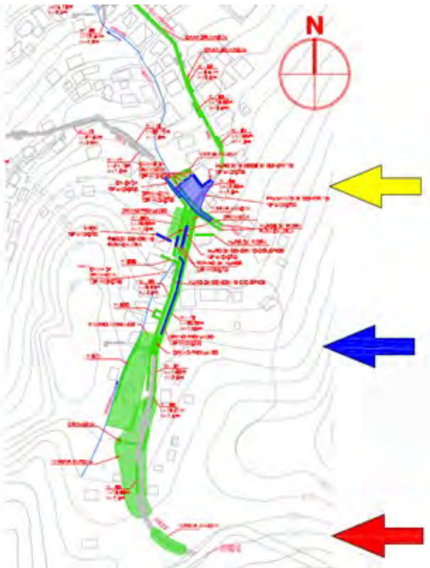

Figure 2 Topographic map of Nova Descoberta Street (between the blue and red arrows, sectors 01 and 02). Source: CGU, 2016.

For Rueda (1999), a model of sustainable water management needs the following principles: the reduction of the extraction of natural resources; the reduction of the pollutant load discharged on the basin; actions for the water economy; reuse of treated water; the use of rainwater; and the reduction of pollutants produced by the discharge of physical, chemical and biological agents into the aquatic environment.

According to Ellis (2010), hydrology must be considered before planning a space intervention so that any settlement can be self-sufficient in water supply (Table 1, items 1.2 and 1.3). This author defends that the Low Impact Development (LID) project is more adequate and cheaper than the conventional urbanization found in Nova Descoberta Street. The LID approach helps to maintain and strengthen the hydrological system of river basins, minimizing the waterproofed surface area, preserving natural vegetation, and reducing the pollutant effluents with local water treatment.

The city's undersized drainage infrastructure was built in the 1970s without a complete urban drainage plan, with shallow runoff and no catchment wells in some parts (Florianópolis, 2015). Nova Descoberta's rainwater drainage network was finished recently and was partially done through concrete pipes, or retaining stony walls. Both mechanisms lead the storm water directly to a local stream. There are no public or private reservoirs for storm water retention, filtration and harvesting (Table 1, items 3.1 and 3.2), despite the existence of a municipal norm that requires that recent buildings must have rainwater reservoirs.

In Florianopolis, some watercourses were straightened, channeled and silted due to lack of proper maintenance (Florianópolis, 2015). In Nova Descoberta, retaining stony walls were built along the local stream and the houses remained close to its border it. Rainwater washes off the street directly into the stream due to the inexistence of Green Infrastructure or other mechanism to retain and filter rainwater before it reaches the watercourse (Table 1, items 3.1). The local stream could have been protected from the impacts of washed-off toxics and pollutants that flow directly in to the stream with the unfiltered rainwater if the public sector had used the LID approach in the area.

In sector 2, land parceling does not follow the natural (topographic) contours of the site (Table 1, items 4.1 and 4.2), sidewalks are absent, and public spaces were waterproofed with concrete (CGU, 2014; 2016). Waterproofing urban soil changes the hydrological cycle, reduces infiltration and groundwater recharge, and increases runoff from rainfall, floods, and pollutant and sediment wash off (Ellis, 2010; Niemczynowicz, 1999). The Treatment Train (Ellis,2010) would minimize the impacts on the water resources in the community. This technique combines Best Management Practices (BMP) and Green Infrastructure by adding different aspects of storm water treatment using vegetation and high drainage covers to intercept, infiltrate and store rainwater (Ellis, 2010; Le Costumer *et al*., 2012; Niemczynowicz, 1999).

In Florianopolis, the sewage network covers around 40% of its districts (Florianópolis, 2015). Individuals or communities try to supply the deficit by building their own septic tanks, infiltration valves or direct launch (Florianópolis, 2010). Due to the recent urban improvements mentioned in this study, Nova Descoberta's sewage network is now connected to a central station, located in the insular part of the city. However, some of the houses in the community are not connected to the public sewage network yet because the responsibility for houses connections belongs to the owners. (Table 1, items 5.1 and 5.2). In addition, the operational capacity of this station was considered outdated in 2012 (TCE / Santa Catarina, 2012).

Farr (2013, pp. 181-189) defends the concept of Living Machines as an alternative to sewage treatment. This author states that these devices are ecologically based equipment, built inside greenhouses. Living Machines, in addition to filtering water, do not use chemicals and allow the reuse of water from the local sewer. Its design also permits the creation of green areas of multiple use, in which it is possible to grow plants, flowers, raise fish, make water sets and extract nutrients for specific purposes.

According to Niemczynowicz (1999), pollution control for water treatment directly on the polluting source facilitates the adaptation of the system to the type of effluent. Therefore, technologies that involve natural biological systems would be suitable for local water treatment in the community (Ellis, 2010; Niemczynowicz, 1999), and temporary water storage could be achieved through swells (Niemczynowicz, 1999). Such devices, as observed by Le Costumer *et al*. (2002), are more cost-effective and durable than traditional filters in removing pollutants and improving water quality and would integrate easily with the urban landscape.

Conclusion

Several authors state the necessity of urban planning combined with hydrology, rainwater management through biofilters, wastewater treatment at the site of the pollutant source, green infrastructures, the combination of traditional water treatment infrastructures with BMPs, rainwater storage and wastewater reuse, as well as the reduction of impermeable areas. However, the construction of the Nova Descoberta Street was carried out without the adequate low-impact environmental design and the government's urban works design completely disregard the environmental vulnerability of the area. Additionally, other problems are worth mentioning: waterproofed public spaces, the lack of sidewalks, disregard for the natural topography of the area in the design of roads and lots, the inexistence of green infrastructures to allow rainwater detention, retention and infiltration, the absence of a local water treatment system and wastewater reuse system, absence of measures to preserve the local stream, and the inadequate hydrological support capacity to sustain the local population.

From an audit's point of view, the recommendation would be to review the suitability of the land-use criteria defined for Nova Descoberta Street and the urban works carried out in the area. It would also be necessary to identify soil disturbance limits, to review land parceling to minimize earthmoving and waterproofed areas surfaces, to use greater drainage capacity coating materials on paved places, to recover and protect the surrounding vegetation and local stream, to include multifunctional and ecological devices to retain, filter and store rainwater, to install wastewater local bio filters and encourage its reuse, and to control erosion and sedimentation. Such measures would mitigate impacts on the hydrological cycle, reduce pollution and urbanization costs (Ellis, 2010; Niemczynowicz, 1999; Le Costumer *et al*., 2012).

The aforementioned methods should not be merely alternative. According to Falkenmark (2011), people need to review water management solutions, and governance strategies should include a more holistic approach. It is important to make stakeholders aware that urban development must combine environmental protection to maintain ecosystem services and sustainable habitability. Public works audits are a useful vehicle for disseminating such ideas as long as they also show the need to implement or reformulate public policies.

However, the results of this research showed that Brazilian public urbanization policy has much to improve regarding sustainable water management. Therefore, more research should be done to improve audits procedures that combine legal, technical and financial compliance analyzes with environmental sustainability assessment. This study also showed that the use of environmental indicators in audit plans is a flexible method that can be applied to any country, where environmental indicators can be selected according to the specific needs of the site, the projects and works that will be analyzed.

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Sustainable Retrofit for Flooding Resilience

Jose Puchol-Salort[1] and Rosa Schiano-Phan[2]

[1] MSc Architecture & Environmental Design, Faculty of Architecture and Built Environment, University of Westminster, London, United Kingdom, pepepuchols@gmail.com
[2] Principal Lecturer, Department of Architecture & Environmental Design, Faculty of Architecture and Built Environment, University of Westminster, London, United Kingdom, R.Schianophan@westminster.ac.uk

Abstract: In recent years, the frequency and impact of flash floods in Mediterranean coastal towns has substantially increased and will continue to rise due to a combination of Climate Change and anthropogenic factors. In 2007, one Spanish town was tragically affected by the Girona River floods, which in few hours severely damaged and destroyed entire buildings. However, despite the severe psychological, physical and economic loss that the population suffered, there is insufficient information and awareness on the risks of recurrence of this phenomenon and the threat that it represents. Previous research studies have proposed to free the riverbed by demolishing buildings and create more green areas. However, an architectural and environmental design approach to retrofit and adapt the damaged housing in order to improve their resilience to extreme climatic events, has never been proposed. The aim of this project is to identify sustainable adaptation strategies for the design and construction of housing buildings affected by the floods. The following studies demonstrated that a series of mitigative and adaptive strategies can be successfully applied not only to prevent flooding and water ingress into building, but also to improve interior environmental conditions in order to maximise comfort and minimise heating and cooling energy demand.

Keywords: Flash-floods, retrofit, sustainable-adaptation, energy-demand.

Introduction

In October of 2007, a huge catastrophe hit the town of El Verger, located in the Valencian Community, Spain. Very strong and torrential rain fell into the higher altitude areas of the Girona river basin due to the *Cold Drop* phenomenon (Camarasa, 2009). The river overflowed in the floodplain area, where several towns are located.

This was not an isolated case, as the Valencian Community is historically one of the regions most affected by flash floods in Spain (Insurance Consortium of Geologic and Mining Spanish Institute, 2006). One of the most important and famous cases is the 1957 flood in Valencia, which completely destroyed the city and killed hundreds of people (J.J.S.I., 2011). It was a catastrophe without precedents, and due to the unexpected consequences of the floods, the Government at that time made a radical decision to dry the Turia river basin on its way through the city (Angus Baker, 2013). Nowadays, this feature makes Valencia the only city in the world to have its green core, activity, and cultural hub located inside an old river basin.

Thus, this project is based around the common and important issue of flash flooding, which due to climate change and human action, will become more and more frequent in the future. Can architects improve the situation and reduce the negative impacts of extreme weather events and increased building construction and urban densification through a climatic and environmentally responsive perspective?

Following a literature review and background research on the responses by local hydrology experts, one of the proposed solutions (Palencia, 2015) was to remove all buildings inside the danger zone, and create green areas around the river, which would absorb rain water and reduce runoff considerably. However, this solution is quite unrealistic and difficult to implement. Apart from the obvious economic impediments, it would have a high-impact on the population. Residents would be required to leave their family houses, and would lose not only their homes but a huge part of their memories and life moments. Nevertheless, another solution, more sensitive to the social context and feasible was proposed and analysed: to **retrofit of the existing housing stock to improve their resilience and comfort conditions**. A good explanation of all problems and consequences of this research can be found in Fig. 1.

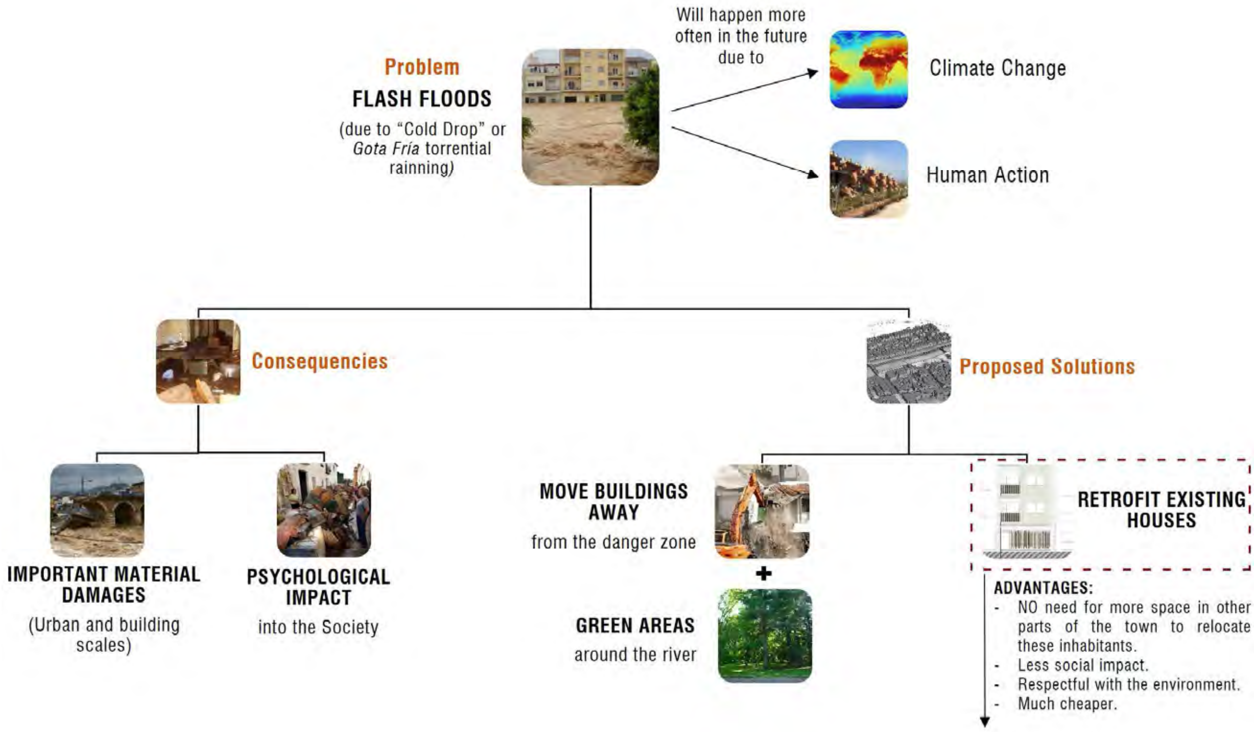

Figure 1. Concept diagram of the main problem, consequences and proposed solutions of El Verger 2007 floods.

Urban Context. El Verger Historic Urban Growth

The Girona River has always been the articulatory axis of El Verger, and the first settlements were located in the area where the church is currently placed. This is precisely located on the highest point of the town, which means that our ancestors were aware that this would be the safest place.

The two maps on Fig. 2, demonstrate that urban density in 1955 was highest on the West part of the river, and the urban tendency during the last 50-60 years has been in the same direction. However, building development started to grow on the other side of the river at that time too, and now these structures shape an important part of the total urban area of the town. In Fig. 2, the urban sections of 1955 and 2016 show this urban density change, especially on the East side of the river. Further, it is important to see how human actions have transformed the riverbed basin. Before it had natural slopes on both sides, and now reinforced concrete walls have been placed, and the width has narrowed.

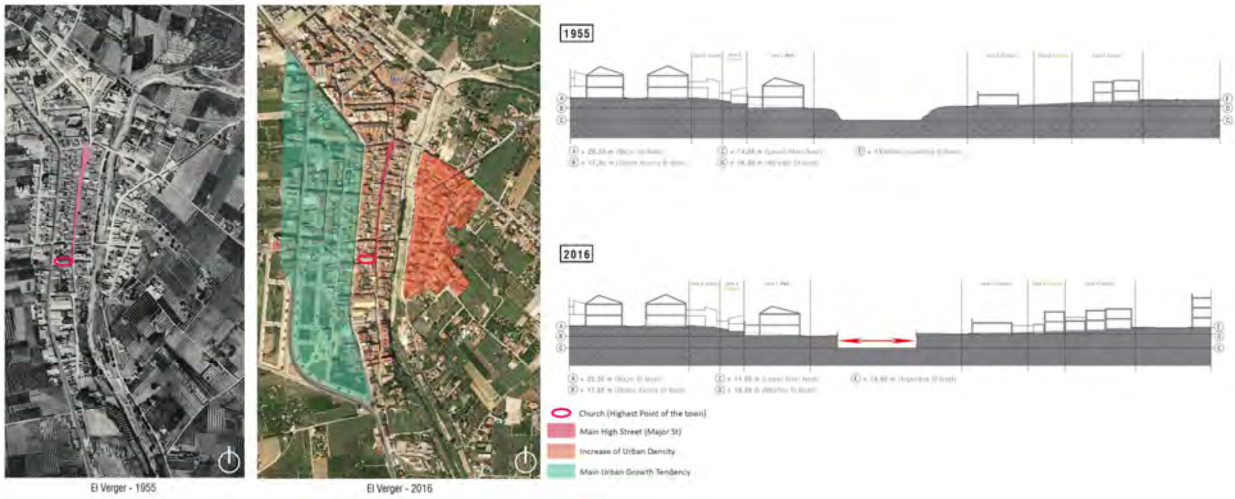

Figure 2. Historic (1955) and present maps of El Verger and urban sections of these periods.

Urban Context. Present

The Planning Authority of El Verger stablished after the 2007 floods, 4 flooding zones depending on the flood water level arrived to every building (El Verger Urban Council, 2015). The first zone is red and it represents the most affected buildings. The level of the water reached the first floors (around 3 m high). The orange zone includes the second most affected buildings and the water reached between 2 and 2.5 m high. The yellow zone is the most reduced zone and the buildings experienced a medium level of flood water, between 1 and 2 m high. Finally, the green zone, includes a large number of houses, which were less affected, but still suffered lots of physical damages. The level in this zone reached 1 m high or less. Based on this zoning, two case studies were chosen as part of this study to investigate more deeply their issues. One case is located in the red high flood risk zone (Case Study 1, a terraced single-family house) and one in the orange zone (Case Study 2, a terraced apartment building), both marked on Fig. 3 (urban cross sections with and without flood water) and Fig. 4 (urban plan of the studied area with floods zones shaded).

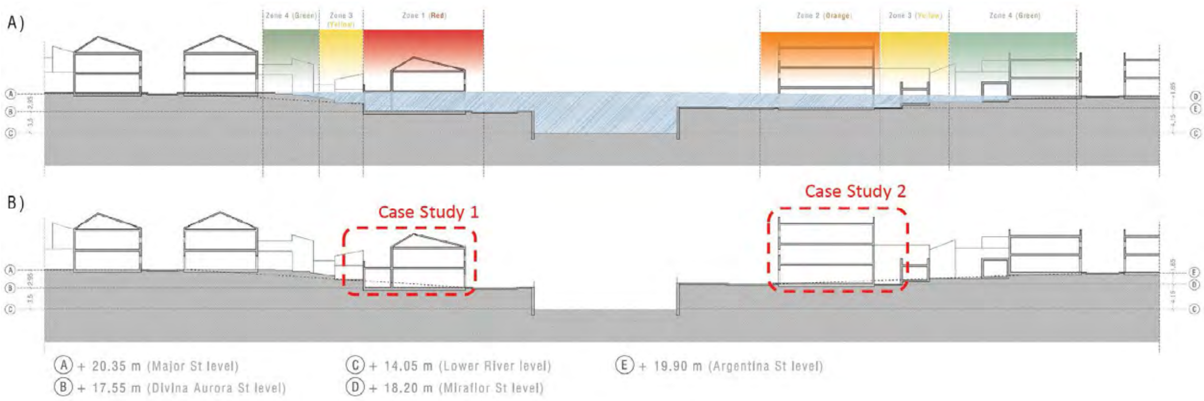

Figure 3. Urban cross section of El Verger indicating (A) flood zones and colour classification; and (B) the two case study buildings.

Figure 4. Urban plan of El Verger indicating flood zones and colour classification.

Climate Analysis

El Verger is included into the mild Mediterranean climate area and as such it presents these general features: a) very mild winters, softened by the sea action; b) long, dry and very warm/hot summers; c) almost 3.000 hours of sunshine per year; d) precipitations in spring and autumn; e) very strong precipitations risk (*Cold Drop*) in September and October; f) No precipitations in the rest of the year; g) High relative humidity (average 65 %); h) Optimal number of hours of daylight (ref). As shown in Fig. 5, where the Valencia Cumulative rainfall is explained comparing present and A1B Future Scenario in 2050, due to climate change, a general reduction in precipitation will be experienced throughout the year. Moreover, the main precipitation data will be concentrated in October creating a “dangerous peak”.

Figure 5. Valencia Cumulative Rainfall: Present (left) and A1B Scenario in 2050 (right). (Meteonorm 7).

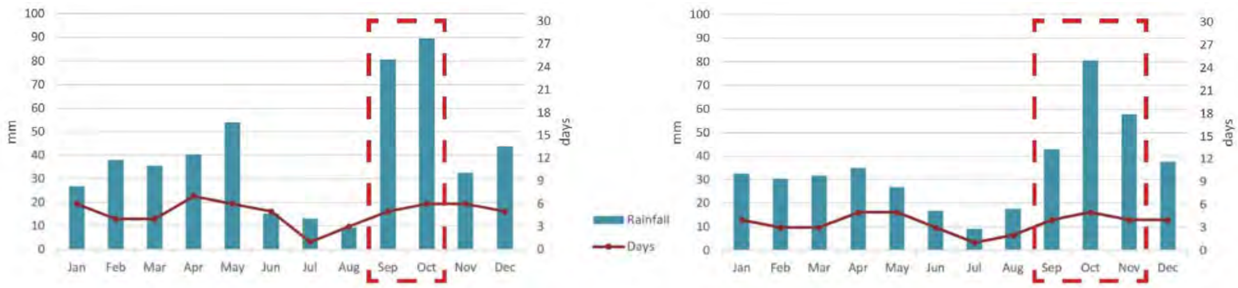

Figure 6. Valencia Relative Humidity: Present (left) and A1B Scenario in 2050 (right). (Meteonorm 7).

Building Scale Analysis

Considering the most typical building typologies affected by 2007 floods and El Verger population pattern, the following cases were selected: 1) one terraced single-family home with one traditional family and 2) one apartment building with one widow grandmother and a single mother with two daughters. Considering all the problems and risks these buildings are exposed to, and after having a broad idea of which are their environmental and climate conditions, one of the most important things to be outlined will be the strategies to be applied. Based on literature review, precedents, fieldwork and urban analytic work findings, the following case scenarios collected on Table 1 have been chosen as best ideas.

Table 1. Cases table which the main design proposals and where are going to be tested, together with the best zones to be applied to.

Case n.	Leaves the water coming inside the building?	Tested on	Best Zones to be applied to
CASE 1. Leave the GF as a semi-open space & move residential spaces to the upper floors + Raise one step the GF and make a drainage floor system	Yes	Case Study 2 Terraced Apartment Building	Zone 1 (Red) Zone 2 (Orange)
CASE 2. Shell around the GF walls + Composite Flood Doors & Windows	No	Case Study 1 Terraced Single-Family House	All zones
CASE 3. Raise two steps the GF level on a Suspended Floor + Optional Case 2	No	Case Study 2 Terraced Apartment Building	Zone 3 (Yellow) Zone 4 (Green)

Design Applicability

Two different techniques were proposed to allow the water being drained easily through the ground and to avoid the damp water rise through the walls or other building elements.

Figure 7. Two steps and a high suspended floor (right) and one step and gravel drainage floor (left) sections.

The first one would be a) to build two steps and a high suspended floor (Case 3, Table 1); and, b) to rise one step into the GF level and create a gravel drainage floor (Case 1, Table 1). Also, compare both strategies on Fig. 7 building sections. Both options are feasible because the current ceiling height is 3.2 m and one of these techniques will only take 0.36 m. Apart from this, the GF doors would be composed by open wooden slats to allow the water coming in (in both façades) (see Fig. 8).

Figure 8. Virtual images of the of the proposed flood resilience design for Case Study 2: Terraced Apartment Building, with and without flood water, as it would be most of the time.

Daylighting Studies

Apart from solving the flooding problems, one of the main goals of this research was to carry out at the same time a sustainable retrofit of the houses affected. One of the important things to reduce the energy demand of the buildings are the daylighting studies. A considerable improvement will be achieved by modifying the interior layout of the apartments. As an example, Case Study 2 apartments have their dining-rooms with no openings to the exterior and they are completely dark and poorly ventilated (Daylight Factor = 0%). Additional strategies will be also applied such as: 1) increase the window to floor area in both elevations (from 7.81% (East) and 9.21% (West) on the main bedrooms to 15%;

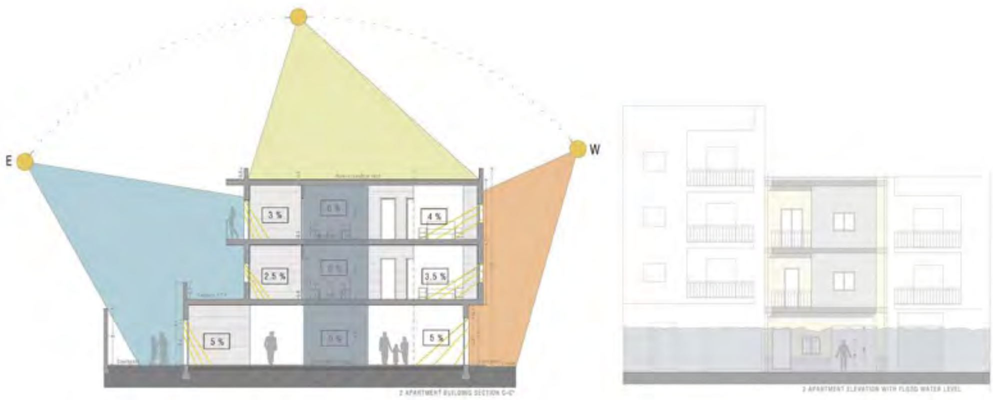

Figure 9. Current section with daylight factor percentages and solar radiation plotted, together with the current elevations with the flood water level arrived to this building in 2007 floods.

2) add two skylights above the staircase; and, 3) build a glass partition into the corridor of the apartments entrances (which before was also completely dark, DF = 0%). Fig. 9 and Fig. 10 illustrate the current and proposed strategies in section and elevation, respectively.

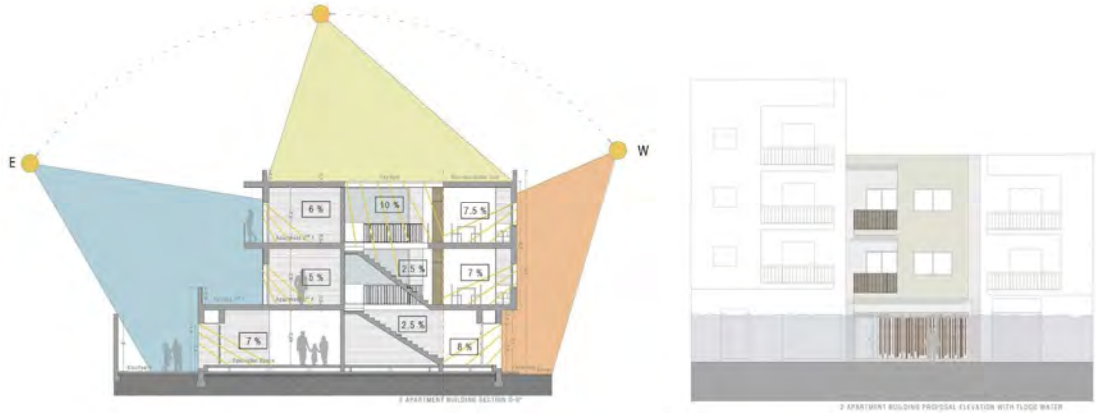

Figure 10. Proposed section with daylighting percentages and solar radiation plotted, together with the proposed elevation with the flood water level arrived to this building in 2007 floods.

Ventilation Strategies and Thermal Performance

Another important aspect to have into consideration to improve the comfort conditions of the interior of the houses and also to reduce some levels of uncomfortable relative humidity, will be to apply several ventilation strategies. Same as before, this will be important to carry out a sustainable design refurbishments. These ventilation strategies are based on cross ventilation (CV) plus stack ventilation (SV) through the stairs skylight, recording before less than 10 ACH (Buoyancy + Wind Driven) and more than 45 ACH after the strategies applied (almost achieving the necessary for cooling on hot seasons). See Fig. 11 to understand this ventilation strategies in Case Study 2 (Apartment Building). This will also be related to thermal performance, because good ventilation levels can reduce significantly the overheating inside of a space and consequently the need for air conditioning (and therefore the energy demand). Thus, the temperatures will drop from more than 30-32°C (in summer) or rise from 12-14°C (in winter) on current situation to be between 19°C to 21°C in all seasons of the year (considered to be inside the comfort band) (see Fig. 12).

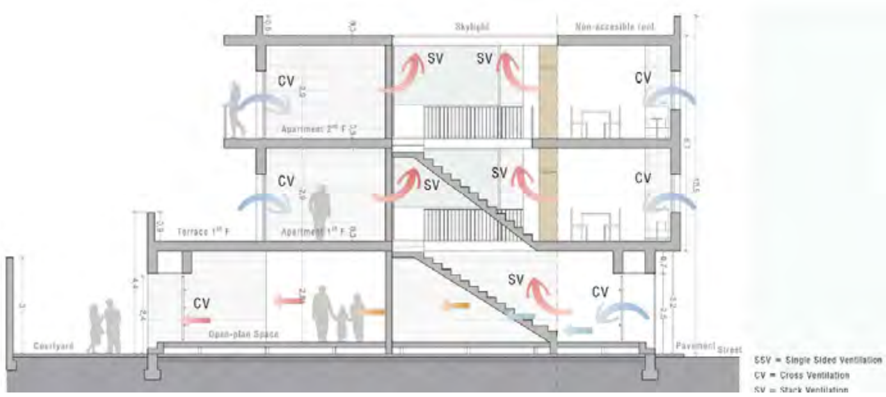

Figure 11. Section of the proposed ventilation system in Case Study 2 (Apartment building) and the different air movements plotted.

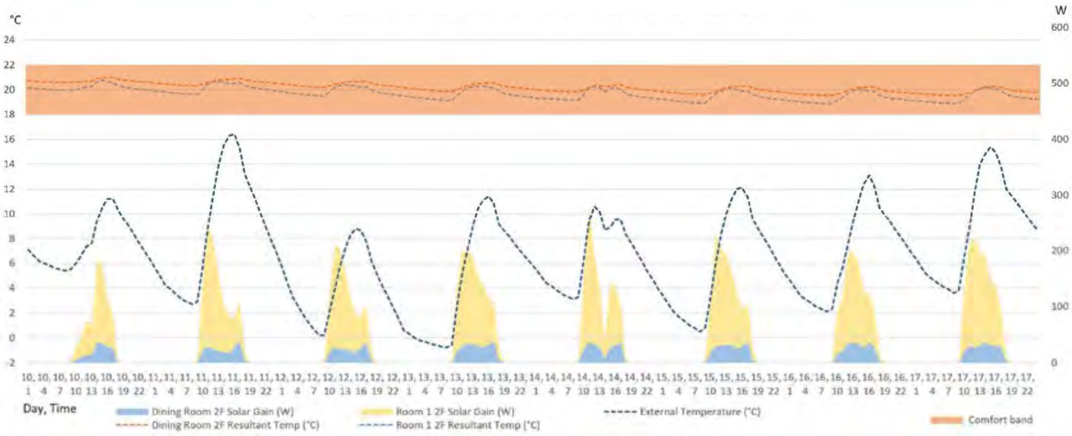

Figure 12. Thermal performance of this case scenario in some of the interior rooms (10-17th January).

Conclusion

Cold Drop affects to all eastern Mediterranean areas and landscape features are almost identical in all cases (relative short river basins with pronounced height difference between its source and mouth). Design interventions studied on this research show that by applying simple strategies to buildings, reducing paved surfaces, creating more interior courtyards, etc. we can significantly reduce the flood damage; and, most importantly, without moving any house or inhabitant. Then, at the same time, if these strategies are made from a sustainable point of view, we can bring all the occupants into a comfort situation almost all year round inside the interior spaces, just changing the W to F ratio, materials or ventilation habits (as we have seen on last sections).

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Water Use and Conservation in Educational Centres of the Federal District, Brazil

Paula Maria Santana[1], Daniel Sant'Ana[1]

[1] Water & Built Environment Research Group, University of Brasilia, Brasilia, Brazil
paulachimba@hotmail.com
[2] Water & Built Environment Research Group, University of Brasilia, Brasilia, Brazil
dsantana@unb.br

Abstract: This paper seeks to understand water use and identify potential water savings for different water conservation strategies in a specific type of school in the Federal District, Brazil. A correlation analysis using quantitative data on metered water consumption, population, built area, built age, garden area and number of sanitary appliances was carried out to understand the main variables that affect water demand in schools. A water audit was carried out in an educational centre to obtain qualitative data on fixture and appliance flow rates, water use habits and water end-uses. With both quantitative and qualitative data-sets, a representative model was composed in order to estimate potential water savings for water efficient equipments and rainwater harvesting systems for non-potable uses. Overall, findings suggest that garden and built area are the most relevant variables that affect school water consumption. Results from water auditing demonstrated that the highest rates of water consumption correspond to leaks (27%) and garden irrigation (24%), suggesting that the main water efficient strategies involves the repair of plumbing leakage and use of sprinklers for irrigation, promoting an annual saving of 681 m^3/year and 1.808 m^3/year respectively. Rainwater harvesting systems were capable of promoting water savings up to 287 m^3/year.

Keywords: Water use, Water efficiency, Rainwater harvesting, Public school

Introduction

The Federal District is under water stress and because of this, the local government determined that all public buildings should reduce their water consumption to a minimum 10% (GDF, 2016). Educational centres represent 15% of all public schools in the Federal District (SEDF, 2013). Hence, it is crucial to identify optimal water saving strategies for an effective water conservation programme in public schools.

Few studies have been carried out regarding water use and conservation in educational institutions in Brazil. (Ywashima, 2005) argues that part of the water consumption in many school buildings is due to leaks and losses. According to the author, one of the main reasons for this, is that managers do not have access to the water bills; these are paid directly by the government. In a later study, (Ywashima et al., 2006) identifies the main water efficient strategies for promoting water conservation in a public school in Campinas. (Ghisi and Marinoski, 2008) conducted a survey that estimated water end-uses at a school in Florianópolis. Based on the data collected, potential water savings were estimated for different rainwater harvesting systems.

The detailed understanding of school water consumption patterns makes way to both development and evaluation of water conservation programmes. Quantifying the amount of water consumed by each individual water fixture and appliance in a school allows us to accurately identify inefficiencies, consumption 'hot-spots' and the uses that offer the greatest conservation potential. However, according to (Vieira et al., 2007), water consumption can vary considerably depending on several factors, such as population, climate, socioeconomic backgrounds and cultural habits. Public schools from the Federal District presents different characteristics from those in previous studies. There is a lack of a data base on water end-use indicators and information on potential water savings for different water conservation strategies in public schools - more specifically, in educational centres of the Federal District. With this in mind, the main objective of this study was to understand water use and identify potential water savings for different water conservation strategies in educational centres of the Federal District, Brazil.

Methodology

As a starting point, a quantitative data was collected by means of remote sensing, on-site observations and questionnaires directed to school directors and building managers for 18 educational centres to collect primary data on metered water consumption, population, built area, built age, garden area and number of sanitary appliances. A correlation analysis using quantitative data on metered water consumption, population, built area, garden area and number of sanitary appliances was carried out using Pearson's correlation coefficient to understand the main variables that affect water demand in schools.

Then, a water audit was carried out in an educational centre, *Centro Educacional 04* (CED 04) in *Guará*, Federal District. Metered water bills were provided by building manager from January 2011 to December 2014 to verify school water consumption. Qualitative data on fixture and appliance flow rates and water use frequencies were used to estimate water end-uses. A full inventory of appliances, fixtures and other water-consuming features was carried out in order to identify sources of water usage, quantify their flow rates and detect any visible leaks. The flow rate of every tap-opening fixture was identified by measuring the time it took to fill up a one litre container by opening the tap half a turn in order to obtain the average flow of a tap, thus obtaining its flow rate. Flow rates of toilets were estimated according to the basin's flushing volume. Toilet flushing and bathroom faucet use frequencies per person were obtained via *in-situ* observations, while kitchen faucet use frequencies were filmed on camera and floor washing and garden irrigation frequencies were obtained through the use of questionnaires.

With both quantitative and qualitative data-sets, a representative model was composed in order to estimate water savings from water efficient equipment and rainwater harvesting systems. For this study, only commercially available water efficient equipments in Brazil were considered for analysis. These included, flow restrictors, automatic bathroom faucets, dual-flush toilets, efficient dishwashers, pressure washers and sprinklers for irrigation. Overall, water savings for these strategies were determined according to their potential water savings, reduced flow rates or consumption loads. In order to analyse the potential water savings from rainwater harvesting systems, three types of non-potable demands were considered for analysis: irrigation and floor washing (Scenario 1); toilet flushing (Scenario 2); and irrigation, floor washing and toilet flushing (Scenario 3). For each of the above rainwater demands, simulations based on daily time intervals using the behavioural model in Equation 1 with a yield after spillage operating rule (Equation 2) for a series of storage volumes was carried out in order to identify water savings for an array of rainwater tank sizes. Three catchment areas were considered according to filter treatment capacity: 200m²; 500m² and; 3000m².

$$V_t = V_{t-1} + S_t - D_t \tag{1}$$

Subject to $0 \leq V_{t-1} \leq C$
V_t = Storage volume at time interval, t
V_{t-1} = Storage volume at time interval, t-1
S_t = Supply during time interval, t
D_t = Demand during time interval, t
C = Storage capacity

$$Y_t = \min \begin{cases} D_t \\ V_{t-1} + S_t \end{cases} \tag{2}$$

$$V_t = \min \begin{cases} V_{t-1} + S_t - Y_t \\ C \end{cases}$$

Y_t = Yield during time interval, t

Results

Based on metered water consumption data obtained from water bills, it is possible to observe a 43% growth in water consumption between 2012 and 2014 (Figure 1). The correlation analysis serves as empirical indications of possible relationships between variables and measure the degree of linear association between two variables. Results shown in Table 1 indicates that water consumption had a very strong relationship with garden area (0.69) and built area (0.64). These correlation coefficients are significant at the 1% or 5% level, that is, they are statistically significantly different from zero at 99% or 95% level of significance. Built age and number of sanitary appliances did not present a relationship with water consumption. Interestingly, population did not present a strong relationship with water consumption (0.30).

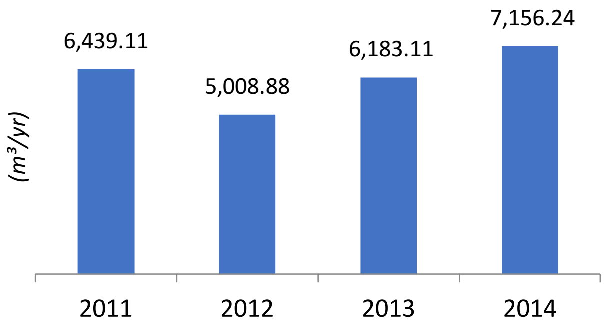

Figure 1: Annual water consumption from 2011 to 2014.

Table 1: Correlation between different water consumption variables.

	Consumption	Population	Built Age	Built Area	Garden Area	Nº Toilets
Consumption	1					
Population	.304	1				
Built Age	.173	.003	1			
Built Area	.643**	-.134	.261	1		
Garden Area	.694**	-.303	.147	.815**	1	
Nº Toilets	-.033	-.299	-.220	.368	.365	1

Table 2 below summarizes values related to the final uses of water in the Guará CED-04, where the estimated consumption for the various water-sanitation equipment of the school was obtained, as well as the values related to losses and leaks. Taking into account the hydraulic audit carried out in the school, the corrected values were also obtained, using a correction factor equivalent to 0.10 based on the difference between the estimated consumption (by the hydraulic audit) and the measured consumption from water meter.

Table 2: Estimated and corrected water end-uses.

END-USES OF WATER CONSUMPTION	Estimated	Corrected
Sanitary Discharge	1416 liters/day	1271 liters/day
Washbasin	203 liters/day	182 liters/day
Drinking fountain	115 liters/day	103 liters/day
Kitchen Sink Faucet	1626 liters/day	1459 liters/day
Irrigation	1747 liters/day	1568 liters/day
Cleaning	244 liters/day	219 liters/day
Losses and Leaks	2005 liters/day	1799 liters/day
TOTAL	7,355 liters/day	6,600 liters/day

There is a predominance of uses related to losses and leaks (27%), irrigation (24%) and sanitary discharges (19%). These three uses correspond to 70% of the total water consumed daily in CED-04, being equivalent to 4,635 litres/day (4,6m³/day). Floor washing and cleaning in general and drinking fountains contribute little to the daily consumption of water at school, accounting for only 5% of daily water consumption (322 litres/day). Water consumption indicators help in understanding the relationship between the quantity of litres of water spent and the population of a given place (consumption *per capita*).

Table 3: Water saving equipment.

Water saving equipment	Amount	Reduction Potential (%)		Base Consumption (m^3/ano)	Reduced Consumption (m^3/ano)	Water economy (m^3/ano)	
Automatic Faucet Sensor with Flow Reducer	9	83	*	490	83	407	
Double Discharge Valve (3/6 lpf)	12	30	*	1099	773	326	
Tap Water Faucet with Flow Restrictor	3	88	*	618	74	543	
Flow regulator	2	28	*	322	232	90	
Industrial Washers	1	99	*	322	3	318	
High pressure washer (2100 W)	1	67	*	37	12	24	
Sprinkler "ECO rotator"	85	87	*	2078	270	1808	
Leaks Repair	---	100	*	681	0	681	
* Based on manufacturer's specifications				5324	1448	4198	**TOTAL**
				100%	27,2%	78,8%	**%**

Solutions to reduce water consumption in schools in the Federal District involve the implementation of water saving equipment, which represents an alternative of greater economic, technical and environmental feasibility for its implementation, such as: flow restrictors and regulators, tidal aerators, double-flush and the automation of the faucets of lavatories and water fountains. For study purposes, the reduction potential, the base consumption, the reduced consumption and the water saving take into account only one equipment per category / environment.

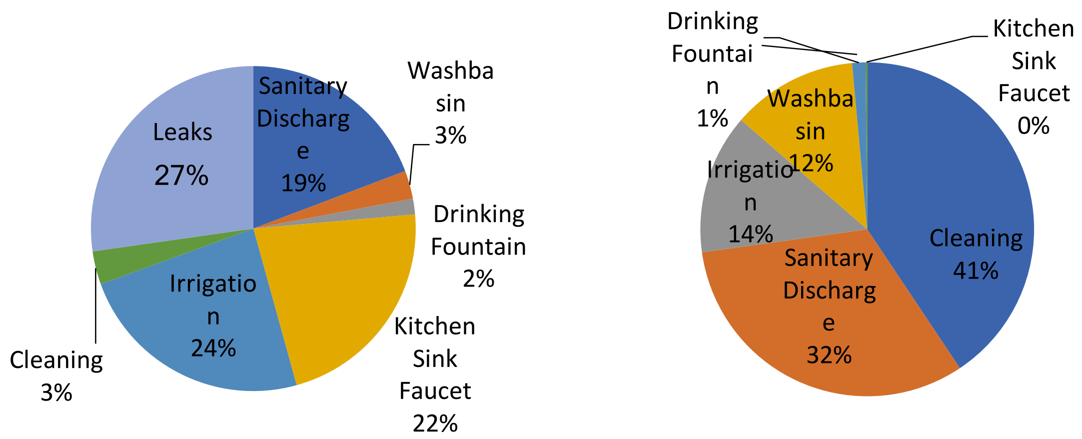

Figure 3: Comparison of end-uses without and with economizing equipment.

Table 4 presents a comparison between the current consumption, called the base consumption, based on the values of the final uses of water corrected and the future consumption, called reduced consumption, based on the values of the final uses of water obtained with the implantation of saving equipment. At first, the comparative table explains the benefits of the implantation of water saving equipment: activities that require the use of water for non-potable purposes are responsible for a daily consumption of 9.229,65 liters (9.3 m^3/day) and after Implementation of the economizadores equipment, the consumption happens to be only 4,714 liters (4,7m^3/day), which represents a reduction of 49%, only with small changes in the existing hydrosanitary equipments in the school.

Table 4: Current consumption (base) and proposed (reduced) water.

Base Consumption		Reduced Consumption	
Scenario 1 ***(liters/day)***		**Scenario 1 (liters/day)**	
Garden Faucet	6.721,24	*Garden Faucet*	2.958,20
TOTAL	**6.721,24**	**TOTAL**	**2.958,20**
Scenario 2 (liters/day)		**Scenario 2 (liters/day)**	
Sanitary Discharge	2.508,41	*Sanitary Discharge*	1.755,89
TOTAL	**2.508,41**	**TOTAL**	**1.755,89**
Scenario 3 (liters/day)		**Scenario 3 (liters/day)**	
Sanitary Discharge	2.508,41	*Sanitary Discharge*	1.755,89
Garden Faucet	6.721,24	*Garden Faucet*	2.958,20
TOTAL	**9.229,65**	**TOTAL**	**4.714,09**

Subsequently, this comparative serves to compose AAP systems that can supply the reduced, but still significant, demand for non-potable water used to carry out the aforementioned activities. In order to analyze and understand the various possibilities of implementation of AAP systems, three different scenarios were proposed where it would be possible to use such systems: scenario 1 consists only of garden faucets used for floor cleaning and irrigation. Currently the performance of such activity consumes 6,721.24 liters of water per day (6.7m³/day), the reduced consumption represents only 44% of current consumption, with 2,958.2 liters / day (2.9m³/day). Scenario 2 is composed of the current consumption of water directed to sanitary discharges, where it is currently consumed 2,508.41 liters of water per day, and the reduction of 30% in consumption results in daily values of 1,756 liters of water (1.7m³/day). Finally, scenario 3 is composed by the combination of the two previous scenarios, which include the three activities considered for the purpose of proposing AAP systems. The values of the base consumption and the subsequent reduced consumption have already been presented above (2nd paragraph). Based on the composition of these scenarios and the decomposition of the reduced water consumption, it was possible to measure several possibilities of AAP systems, based on factors such as water catchment area of the roofs of the school, capacity of the cistern, based on filtration capacity, and economy of Water (m³/year).

Scenario 1 demonstrates four different simulations: the first is the simulation of the necessary capacity of the cistern for the basic consumption (without saving equipment) with rainwater catchment area of 200m². To achieve 100% efficiency, which corresponds to a saving of 130m³ / year, a cistern with a capacity of more than 59m³ is required: the simulation indicated a cistern with a storage capacity of 109m³. The last simulation of scenario 1 takes into account reduced consumption (with saving equipment) and a catchment area of 200m². Note that in this case the maximum efficiency is reached with a cistern with a capacity of 7m³.

For scenario 2, six simulations were required, since the demand for water consumption for sanitary discharges is higher. The first simulation, with baseline consumption and water catchment area of 200 m², resulted in a water saving of 157m³ / year when maximum efficiency was reached. This would require a cistern with a storage capacity of 50m³. The final three simulations concern the reduced consumption, whose maximum efficiency represents an economy of 110m³ / year. The fourth simulation considers a catchment area of 200m², where maximum efficiency is achieved with a cistern with a capacity of 30m³. The fifth simulation, which considers a catchment area of 500m² requires a cistern with the capacity to store 19m³. Finally, the last simulation for reduced consumption, which considers a catchment area of 3,000m², where a cistern containing only 2m³ of water is needed.

The last scenario is the junction of the first two, so it has a greater demand for water. The first simulation, which takes into account the baseline consumption and a rainwater catchment area of only 200 m^2, did not present plausible results to obtain efficiency Maximum, which corresponds to an annual reduction of 287m³, instead showed a maximum efficiency of only 63%, which corresponds to an annual saving of 180m³ and cistern with capacity for 69m³ of water. The three simulations with the reduced consumption were also satisfactory, since all reached 100% efficiency: the first with a catchment area of 200sqm and a cistern of 46m³. The second with a catchment area of 500m² and a cistern of 29m³ and finally the last simulation, with a rainwater catchment area of 3,000m² and a cistern of only 3m³.

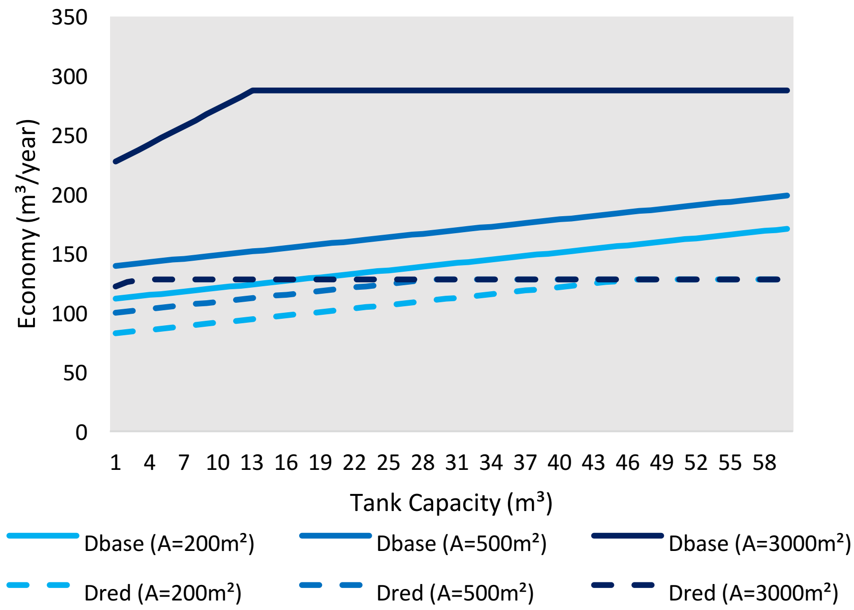

Figure 3: Comparison of end-uses without and with economizing equipment.

Conclusion

With the analysis of qualitative and quantitative data, it was possible not only to identify and categorize end-uses of water and to understand the habits related to floor washing, irrigation and sanitary use. On the other hand, data on end-uses of water made it possible to propose specific water-saving equipment for each activity carried out in the school, in order to reduce water consumption. In addition to the implementation of water saving equipment, the composition of several scenarios that simulate the implementation of AAP systems has increased the potential of reducing water consumption for non-potable purposes.

With the implementation of water-saving equipment in Guará CED-4, a potential reduction of 78.8% in annual water consumption is predicted, which represents an annual value of 4,198m³. Considering the same reduction potential for the other schools interviewed, a water saving of 75,564m³ per year is estimated. This value is extremely significant, since it demonstrates the effective reduction of water consumption with simple measures.

With the reduction of water consumption through the implantation of water-saving equipment, a new configuration of water consumption was achieved in its final uses. Then, it was proposed the implantation of AAP systems in order to utilize the rainwater, currently discarded. The composition of three different scenarios allowed the simulation of different configurations for the same AAP systems. This measure was taken in the future to address as many schools as possible, considering the different typologies of existing buildings and also considering the future financial implications that the implementation of such systems may entail. With the proposition of cisterns with different storage capacities it is possible to make several adaptations that aim to meet the best possible way the individual demands of each school that will make use of this study in the future. Also demonstrating that it is possible to reach the maximum efficiency of the system even in a climate less prone to rainfall, as is the case of the Federal District, which is considered of great importance for future studies in the area, as well as for the real implementation of these systems in several public buildings in the capital.

The present article makes it possible to carry out future studies aimed at deepening the studies already carried out, especially regarding the concomitant use or not of water saving equipment with AAP systems, taking into account the technical, economic and environmental feasibility of each alternative.

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Social-Ecological-Technical Systems in urban planning for a Circular Economy: an opportunity for horizontal integration

Janneke van der Leer[1], Arjan van Timmeren[1] and Alexander Wandl[1]

[1] Chair of Environmental Technology and Design, Department of Urbanism, Faculty of Architecture and the Built Environment, Delft University of Technology, Delft, the Netherlands, j.g.g.vanderleer@tudelft.nl

Abstract: Circular Economy (CE) is receiving interest worldwide as a way to overcome the currently dominating linear and wasteful production and consumption model of our environment. Currently the implementation of CE to practice is still in an early stage. As hubs of consumption and to a more limited part also production, metropolitan areas often are seen as crucial to achieve the transition towards a CE. Therefore it is necessary to find ways to integrate a CE based approach in urban planning practice. This paper reviews literature dealing with the concept of CE by making use of a framework for urban planning to evaluate integration of vertical and horizontal dimensions in CE literature. This paper reviews the scales of CE as regarding vertical integration, while for horizontal integration the sub-systems that need to be integrated are investigated. Thereafter, the framework is used to evaluate existing CE urban planning documents of the Amsterdam Metropolitan Area and surroundings.
The paper aims to contribute to the comprehension of the concept of CE for the urban planning practice. This understanding enables urban planners to integrate CE in their work and aims to contribute to further accelerate the implementation of CE in metropolitan areas.

Keywords: Circular Economy, urban planning, integrated approach, SETS, Amsterdam Metropolitan Area

Introduction

Circular Economy (CE) is receiving interest worldwide as a way to overcome the currently dominating linear and wasteful production and consumption model of our society. In the last decades CE has become an important and significant new school of thought in sustainable development aiming sciences (Murray et al., 2015), however the implementation of CE worldwide is still at an early stage of development (Ghisellini et al., 2016) while there are only few studies on the concept (Jurgilevich et al., 2016). Most of the times Circular Economy (CE) is studied and treated only as an approach to more appropriate waste management (Ghisellini et al., 2016). However, CE is more than optimized waste management and could be used to understand and implement new models for sustainability and wellbeing with low or no material, energy and environmental damages (ibid). A comprehensive definition of CE is provided by Murray et al. (2015, p. 377): "an economic model wherein planning, resourcing, procurement, production and reprocessing are designed and managed, as both process and output, to maximize ecosystem functioning and human well-being".

To realize CE on larger scale a radical change, or even a paradigm shift, is needed (Bonciul, 2014; Lieder and Rashid, 2016). The implementation of CE is challenging because of the current linear mind-set and the structures in industry and society (Lieder and Rashid, 2016) and because it requires changes in different sub-systems on various scales (Van Buren et al., 2016). Metropolitan areas often are seen as crucial to achieve the transition towards a CE (Van Timmeren, 2013; Cohen and Muñoz, 2016; Owen and Liddell, 2016) as they are the hubs of consumption and to a more limited part also production, while at the same time the environments that are faced with scarce resources and insufficient infrastructure capacity (McLaren and Agyeman, 2015).

Metropolitan regions can, as every other complex system, be described by the conceptual framework of panarchy (Gunderson et al., 1995; Gunderson and Holling, 2002; Holling et al., 2002) which accounts for the duality of stability and change in which complex systems of people and nature are dynamically organized and structured across scales of space and time (Allen et al., 2014). It is important to find ways to incorporate a CE based approach in urban planning practice (Owen and Liddell, 2016). Urban planning is an integrative discipline: it needs to integrate physical, social-cultural infrastructure, the economy and the environment (Rotmans et al., 2000; Karvounis, 2015). According to He et al. (2011) urban planning can be defined as an interdisciplinary and comprehensive approach for a balanced regional development and physical organization of space. The aim of this paper is to identify possibilities for the integration of CE principles in urban planning.

Methodology

In order to identify how to integrate a CE approach in urban planning it is necessary to understand first the integrative dimensions of urban planning. Urban planning aims to change or manage spatial development by constructing new ideas, visions, actions, means for implementation, processes and other ways of understanding (Albrechts, 2006a, 2006b). It is an integrative discipline in which often two (organizational) dimensions are discerned: horizontal integration and vertical integration (Stead and Meijers, 2009; Holden, 2012). The horizontal integration has the aim to deepen specific knowledge (Albrechts, 2006a) and emphasizes “collaboration, coordination and the building of working relationships” (Albrechts, 2006b) across policy domains, local agencies and departments (Hajer and Zonneveld, 2000; Stead and Meijers, 2009). The vertical integration is related to linkages between different scale levels (Albrechts, 2006b), levels of government, like national, provincial and municipal (Hajer and Zonneveld, 2000) and different tiers of government (Stead and Meijers, 2009). Figure 1 illustrates the horizontal and vertical integration in urban planning.

This urban planning framework is used to evaluate how the concept of CE can be integrated in urban planning, by investigating vertical and horizontal dimensions and related aspects in CE literature. Zhijun and Nailing (2007) introduced the vertical and horizontal dimension in the context of CE and stress the integration of different scale levels vertically and the integration of different sub-systems horizontally for a practical implementation of CE. Based on this approach, this paper reviews the scales and approaches of CE as regarding vertical integration, while for horizontal integration the sub-systems that need to be integrated are investigated. Thereafter, a framework to evaluate which aspects of integration a specific planning document considers is presented and used to classify four existing CE urban planning documents of the Amsterdam Metropolitan Area (AMA) and its surrounding region.

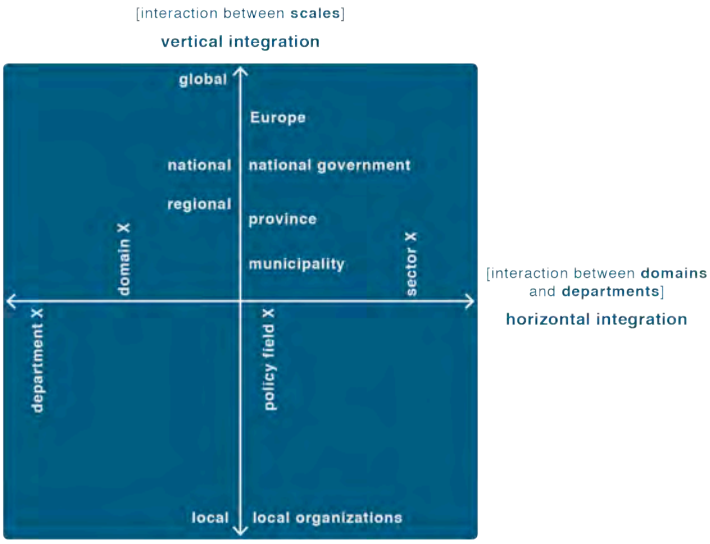

Figure 1: integration in urban planning

Towards a framework to understand opportunities for integration of CE in urban planning
Vertical integration of scales

CE is rooted in environmental economics and Industrial Ecology (Ghisellini et al., 2016). In many CE studies the concept is related to determined spatial scales and these scales are built upon frameworks known from Industrial Ecology (Yuan et al., 2006; Murray et al., 2015). The following three scales can be discerned regarding research in relation to CE: micro level (individual company level), meso level (eco-industrial network level) and macro level (city, municipality, province or state)(Yuan et al., 2006; Ghisellini et al., 2016).

The development of CE has a potential to raise awareness and creativity on a more local level, therefore, adaptive governance may be an important force in the transition to sustainable pathways in cities (Van Timmeren, 2013). A very important result of localization of CE is that the use of resources together with the problems arising from our lifestyles and consumption patterns will become more apparent and transparent to the public at large. Hence, the distance between awareness and action can be decreased (ibid). Therefore, the integration of efforts at all three scale levels is necessary for a successful implementation (Su et al., 2013). However, for material flows and systems, it is hard to determine specific scale levels. As cities are dependent on their (global) hinterland, where extraction and transformation processes take place (Barles, 2014) and for provision of resources, goods and services, it is difficult to determine which scale is specific to which flow (Weisz and Steinberger, 2010). Van Buren et al. (2016) explain that transitions not only need to take place at the regional and national scale, but also at the European and even global scale for implementing a CE. To conclude, the relevant scale to support CE in urban planning depends on the resource flow and the nature of the intervention (Voskamp et al., 2016) and thus often multiple scales and reaches are involved.

Vertical integration of approaches

In some countries, like for instance China, the implementation of CE is a result of a top down approach, while in the transition towards CE in Europe often a bottom up approach is taken (Ghisellini et al., 2016). However, for successful implementation of CE an integration of bottom up and top down approaches seems necessary (Mathews and Tan, 2011; Lieder and Rashid, 2016). It also relates to the 'Sandwich Strategy' by Tjallingii (1996) which according to him is necessary for far-reaching support of the sustainability and perhaps self-sufficiency of the various structures and infrastructures in spatial planning. The strategy distinguishes a basic layer (the users). Decentralized initiatives to solutions and environment-friendly behaviour are emphasized here. These decentralized initiatives are facilitated by the central government, which sets up conditions top-down through goal-oriented system dynamics (Van Timmeren, 2006).

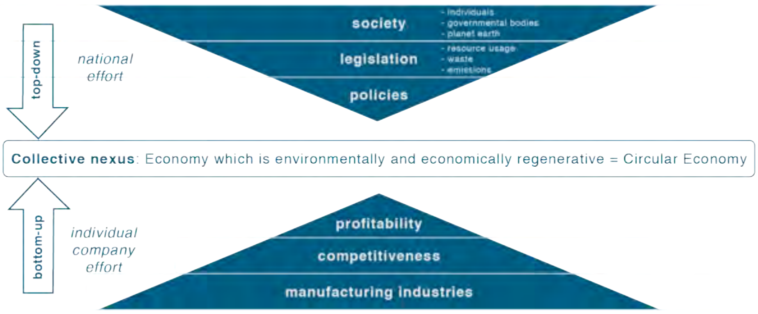

Figure 2: proposed CE implementation strategy applying top-down and bottom-up approach, adopted from Lieder & Rashid (2016)

In the model of Lieder & Rashid (2016), see figure 2, a concurrent approach to implement CE at large scales is proposed. The model is based on the assumption that "inverse motivations exist among the stakeholders of CE which need to be aligned and converged" and is similar to the strategy by Tjallingii (1996). Lieder and Rashid (2016) see top-down as a national effort by society and governmental bodies and bottom-up as the efforts by individual companies.

Horizontal integration of sub-systems

In recent CE literature, the integration and redesign of four sub-systems is mentioned regarding CE in cities, provinces or regions (Zhijun and Nailing, 2007; Ghisellini et al., 2016): the industrial system, the infrastructure system, the cultural framework and setting and the social system. These four sub-systems together constitute a larger complex system (Dammers et al., 2014). However, Voskamp et al. (2016) suggest in line with Haken (1983) that the complexity of urban systems (related to resources) should be described by integrating the quantitative knowledge of resource flows with the environmental, social and economic understanding. Research into complex systems is often divided in social-ecological systems and social-technical systems. Social-technical systems can be described as clusters of elements, like technologies, regulations, infrastructures, institutions, supply networks, markets, social practices and cultural meaning (Geels, 2005; Da Silva et al., 2012; Kern, 2012) that are constructed to be controlled (Pahl-Wostl, 2007) and that are highly institutionalized to realise societal functions (Smith et al., 2010). At the core of a social-technical approach is the interaction between technologies, material artefacts and human activity and actors (Mylan et al., 2016). Social-ecological systems can be described as human activities and associated water, energy and chemical fluxes (Ramaswami et al., 2012). Social-ecological systems aim at integrating ecological and social sciences to study coupled human and natural systems (Liu et al., 2007). Feedback and interaction between ecosystems and humans are key in social-ecological systems. A better understanding of the processes of human-environment interactions that affect the resource flows of cities is essential for sustainable resource management (Van Timmeren, 2006; Pahl-Wostl, 2007; Voskamp et al., 2016). Next to the suggested sub-systems in actual CE literature, concerning mainly social-technical sub-systems, incorporating social-ecological sub-systems as well, seems relevant.

An integrative CE evaluation framework for urban planning

Based on the vertical and horizontal integration, a V-H CE evaluation framework is suggested for urban planning, see figure 3. The framework aims for an integrative multi-scale, multi-disciplinary and systemic approach in which bottom-up and top-down efforts reinforce each other. This is in line with the suggestion by Voskamp et al. (2016) that for resource-conscious urban planning a multi-scale, systemic approach is needed to provide the required information on resource flows and the interlinkages between processes and resource flows.

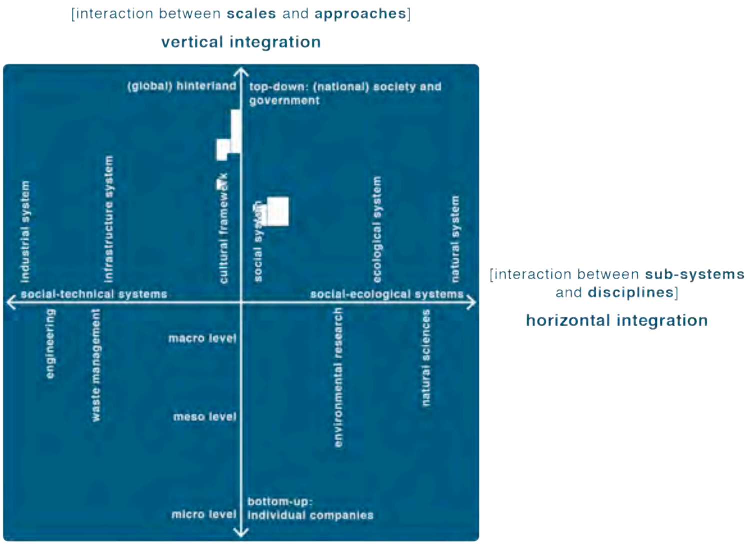

Figure 3: V-H CE evaluation framework for urban planning

CE urban planning document analysis of the Amsterdam Metropolitan Area

In order to understand how CE aiming strategies for urban planning are functioning in planning practice, four CE urban planning documents for the Amsterdam Metropolitan Area (AMA) and its surrounding region are evaluated according to the V-H CE evaluation framework. See figure 4. For vertical integration of scales focus was put on the arrow and for vertical integration of bottom-up or top-down approaches a triangle was used in the box of the document. Horizontally we focused on the interactions between sub-systems. The documents were analysed and key words found in relation to the vertical and horizontal integration in CE literature are used to determine the position in the evaluation framework.

From the analysis of the CE planning documents for the AMA and surrounding region it becomes apparent that the vertical integration of scales is often taken into account in the documents. At the same time, the integration with the (global) hinterland is often lacking in the documents. The vertical integration of top-down and bottom-up efforts is mentioned in two documents. The other documents focus on top-down efforts only. It can be concluded that vertical integration in CE planning documents for the AMA is partly taken into account. In the horizontal dimension however, less integration is taking place. Most of the documents have a social-technical focus and do not take the social-ecological systems or interactions into account. In document 02 and 03 some attention is devoted to ecological impacts. From figure 4 it becomes clear that the horizontal integration is not yet sufficiently embedded in current planning documents for a CE in the AMA and surrounding region.

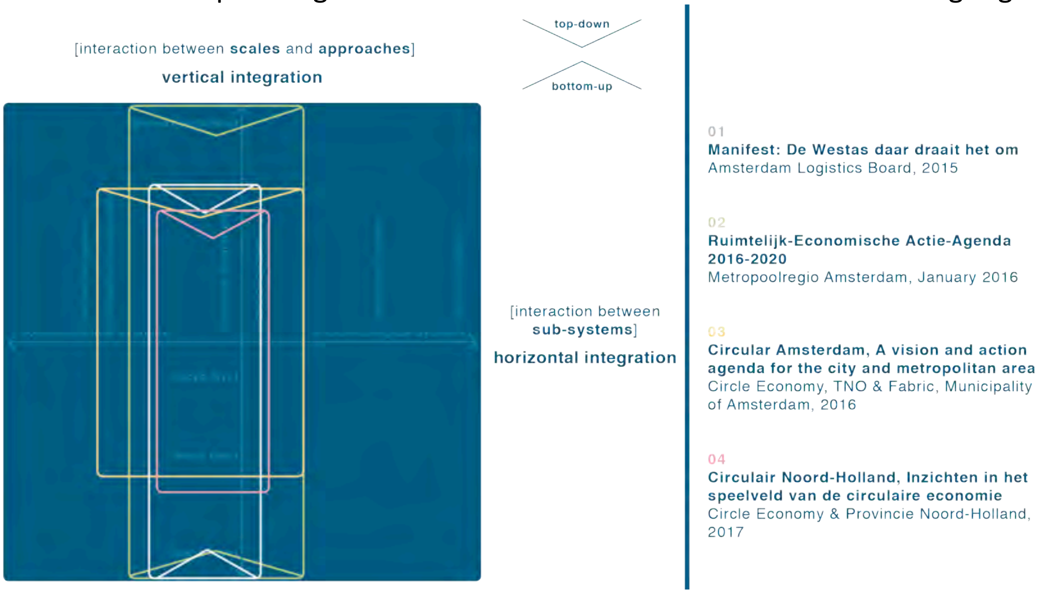

Figure 4: CE planning documents for the AMA in the V-H CE evaluation framework for urban planning

Discussion

There is a lack of horizontal integration of sub-systems in the AMA context, an presumably in other areas as well. A next step in the development of successful CE strategies in urban planning is that the current focus on social-technical systems of the planning documents related to CE for the AMA and surrounding region needs to be integrated with social-ecological principles. Wilkingson et al. (2013) show that a social-technical approach has been a traditional way to analyse urban complexity and that a social-ecological approach needs to be integrated. By combining and integrating a social-technical and a social-ecological approach a so-called SETS (social-ecological-technical-systems) approach can be achieved, in which social, ecological and technological aspects of environmental phenomena are considered leading to a better understanding, support and management of urban ecosystems (Ramaswami et al., 2012; Groffman et al., 2016). Ramaswami et al. (2012) point out that "complex, cross-scale interactions between the natural system, the transboundary engineered infrastructures, and the multiple social actors and institutions that govern these infrastructures" are necessary for the sustainability of city systems. The main challenge is the further development of this multidisciplinary approach, the integration of theories and methods of the engineering and design disciplines with the natural and social sciences (Groffman et al., 2016) and the implementation in the urban planning practice. Our current urban systems were built upon and exist within the paradigm of waste. There are many opportunities for investment into environmental technologies to achieve CE, such as cogeneration systems, biogas and anaerobic digesters for the purpose of harnessing essential flows of nutrients and recycling of clean water. Research into the feasibility and integration of CE for the built environment discovered numerous positive outcomes as long as systems are reciprocal and synergistic, building upon communities and the local natural environment. Or, differently stated, address both horizontal integration as well as vertical integration. While CE might not solve climate change and resource scarcity, it offers opportunities for planning and design of new and existing areas based on the principle of decentralized, interconnected, polycentric circular urban systems. Not only will urban planners need to re-examine traditional political and geographic boundaries, but the scalability of solutions, infrastructure, interrelated networks and the role of public space as well.

Further research is needed to investigate how the understanding of systems can be incorporated in urban planning and how a SETS (social-ecological-technical-systems) approach can be taken in urban planning for a CE. In such research, the development of methods to incorporate SETS and systemic approaches in urban planning of metropolitan areas is key.

Acknowledgements

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Design to Thrive

Water Policy and Institutional Development: Meta-Analysis for Informed Policy Development in Punjab, Pakistan

Zehra Waheed[1], Muhammad Muneeb Ahmed[2]

[1] Suleman Dawood School of Business, Lahore University of Management Sciences, Pakistan
zehra.waheed@lums.edu.pk
[2] Suleman Dawood School of Business, Lahore University of Management Sciences, Pakistan
muhammad.muneeb@lums.edu.pk

Abstract: Economic development cannot be achieved without water. Water has helped drive modern-day economies through agriculture, industry, energy production and the maintenance of general quality of life. Currently, developing South-Asian economies like Pakistan are seeing burgeoning populations and rapid urbanization coupled with economic growth. Yet despite Pakistan becoming water deficient over a decade ago, policy and institutions surrounding water management remains fragmented and water is still considered a free good available in abundance. Resultantly, policy transitions emerging out of the socio-technical nature of water management and the need for integrative water resource management across different sectors has been slow. This paper describes output from an ongoing research project classifying actors according to roles, dependencies, influence and interests using qualitative and methods and Social Network Analysis. Grounded in the theory of networked governance and stakeholder theory, this paper presents the first part of the research findings, a situational analysis that explores the current state of affairs, constraints and enabling conditions for policy surrounding WRM in large urban centres of Punjab, Pakistan. Findings reveal that weak governance structure, poor capacity and lack of service focus have unfavourably impacted water aquafers as well as ground water utilization in Punjab. These conclusions have relevance for regional and local institutions as well as international funding bodies involved in the development of urban water infrastructure and policy in South-Asia.

Keywords: policy, water, actors, stakeholder interests, SDGs

Introduction

As developing countries continue to see rising middle class incomes and economic growth, household per capita water consumption is also on the rise (see Cosgrove and Rijsberman, 2014; Rijsberman, 2006) as well. Higher consumption patterns and burgeoning populations in developing countries also translate into higher demand of water for electricity generation, agricultural and livestock production as well as domestic and industrial consumption. This is leading to depletion of freshwater resources and ensuing water stress (Rijsberman, 2006).

Effective maintenance of water has been cited as one of the most significant factors contributing towards sustainability (e.g. in Schaffer and Vollmer, 2010) but while developed countries have been compelled to revisit their traditional methods of operations because of increasing environmental awareness, climate change, rising energy prices, population changes and the emergence of more complex regulatory frameworks (Marlow et al., 2010), the push factors in counties like Pakistan have been tempered with pragmatic constraints such as resource scarcity and an aging infrastructure that requires expensive replacement. Although the challenges faced in the first world are formidable, those faced by the developing world are arguably even greater, given that such countries have yet to reach the levels of socio-technical, managerial or regulatory sophistication that the developed world takes for granted. Urban centres in developing countries continue to struggle with what is called a 'brown agenda' i.e. issues pertaining to environmental health impacts- something the developed world overcame long ago- as opposed to what Allen et al. (2002) refer to as the 'green agenda' which the developed world now aims at. The situation is made worse by the fact that urban centres in developing countries are expected to continue to grapple with phenomenally high levels of urbanization and economic activity: both of which put pressure on water resources and service provision.

In Pakistan- a country battling with insurgency, terrorism and political instability- water scarcity is rarely highlighted as one of the most difficult issues challenging increasingly affluent, modern Pakistan. The country's growing, consumptive middle-class drives the hunger for production, energy and food- all directly or indirectly dependent on water. Pakistan's cities are urbanizing at a rate of 3% pa—the fastest in South Asia (Kotkin and Wendell Cox, 2013)[1]. However, cultural urbanization appears to be taking place in the country at a much faster pace than urbanization per se. Advances in information and technology, market development and exposure through media have altered rural locales into product-and-service-hungry 'virtual' cities (Iqbal, A, 2014). As access to water, electricity, natural gas and public services improves, rural lifestyles too are changing. This all leads to pressure over water- which is a primary input in food, energy, domestic and industrial production systems. These huge demands on water resources in the country are leading to groundwater depletion (at some places annual fall in aquafer level is almost 1 meter), turning rivers into wastewater streams and deteriorating water quality. Punjab (and Pakistan), however, are not alone in facing such a scenario. UN-Water's 'Water for a Sustainable World 2015' report (UN-Water, 2015) has identified poor groundwater maintenance, lack of institutional capacity and governance mechanisms as key causes of water problems in South Asia region.

Policy transitions in other developing countries have focused on different paradigm shifts. India and Indonesia have aimed for decentralization, and participatory governance, Turkey and Tanzania have transitioned to policy focusing liberalization of water services, while Thailand expects to move from all-year-all-year-around irrigation and farm-to-city water supply (Meijerink, S., 2009). Pakistan (and Punjab in particular) is aiming at sustainable groundwater management and improved service delivery. In lieu of this, several policy interventions have taken place over the last decade at the federal level as well as in Punjab, the most affluent province. Federal policies tend to trickle down into provincial policies, however Punjab has been progressive beyond the narrative provided by the federal government in terms of not only clear policy interventions but also improved service delivery through the establishment of independent water supply companies for rural supply.

Taking Punjab as a case study, this paper presents policy interventions in the water infrastructure sector and reports preliminary findings from a research project investigating the water sector dynamics in Punjab and classifying actors representing different levels of government and water sectors (e.g. urban water supply, industrial supply, rural supply, wastewater management and agriculture) integrate and ways in which this 'water network' supports or hinders current policy initiatives. The presents a situational analysis of practice in

[1] One can get a real sense of this unusual urbanization by considering the population of Karachi- the country's most industrialized port city- which grew by 80% in the decade ending 2010; the largest rise of any city in the world.

Punjab, that sets the base for primary data collection and analysis leading to the network governance framework (see Jones, C., Hesterly, W.S. & Borgatti, S.P., 1997).

Unsustainable Growth

The author's core argument behind presenting this situational analysis is that unsustainable development pathways being followed in Punjab, coupled with failures of local and regional government have put immense pressure on water resources in urban environments such as those on Punjab. This unregulated growth is beginning to effect water availability, quality and equitable distribution already despite most of Punjab benefitting from one of the largest underground freshwater aquafers in the world. The situation therefore compromises water's role in generating economic and social benefits for the region- an effect quite opposite to the one intended. Like most of the world's growth since the 1960s, economic growth in Punjab has also come at the cost of environmental and social degradation- aggravated by poor policy and governance mechanisms. A major hurdle in way of improving water service delivery in Punjab has basically been was the weak articulation of an urban sector vision and policy and an inherently inefficient structure of service provision (see World Bank, 2013).

The reason behind this has been the state's fixation on asset creation rather than the quality of services from those assets and demand-side management. Despite the relatively high levels of access to improved infrastructure in Punjab (such as filtration plants and pumping stations), the quality of access to services and an equitable distribution of services is poor and deplorably low. Like in many other developing countries, the thrust in has been on physical infrastructure rather than quality of services. Both the government and its development partners such as the Asian Development Bank and World Bank have put policy and reform on the back burner, while focusing on infrastructure upgradation almost entirely. There is therefore a need to promote a very different planning and policy paradigm: one that focuses on service, sustainability and value rather than asset creation through a fragmented developmental process. The need is to develop an urban sector vision that promotes an efficient structure of service provision.

Punjab (and Pakistan), however, are not alone in facing such a scenario. UN-Water's 'Water for a Sustainable World 2015' report (UN-Water, 2015) identifies poor groundwater maintenance, lack of institutional capacity and governance mechanisms as key causes of water problems in not only Asia-Pacific, but the Arab as well as Latin American regions. Recent international studies such as Zhang (2010) have shown the advantages of making urbanization work well and the firm role of effective planning and good governance in building thriving, productive, liveable cities.

Governance and Policy

Punjab's performance in most Millennium Development Goals (MDGs) indicators was far superior compared to other provinces. While the province either reached, or was close to achieving its annual targets for 2015, for most indicators, Punjab remained off track in achieving the targets (UNDP, 2015). Now that MDGs have run their tenure and are being followed by a wider-encompassing Sustainable Development Goals (SDGs), Punjab will need better policy and political will to meet the necessary targets, which it failed to meet with its MDGs. Water is targeted through multiple SDGs. SDG 1 (ending poverty) requires equitable distribution of freshwater. SDG2 indirectly includes water (sustainable agriculture). SDG 3 (well-being) requires clean drinking water provision for all. It is SDG 6 that explicitly puts water on the table: ensuring availability and sustainable management of water and sanitation for all. With targets set for 2030, Punjab must pull its act together and fast.

The government, conscious of the MDG situation, had launched a policy and institutional reform initiatives to address bottlenecks. In 2006, the Government of Punjab established an exclusive think tank to work in an advisory capacity on urban issues in Punjab. The “Urban Sector Planning Management Services Unit” (USPMSU) was given a mandate to respond to legal, institutional, technical and management needs of line departments and cities in Punjab. In 2008, the Government of Sindh replicated the Punjab model and established a “Directorate of Urban Policy and Strategic Planning”. In 2009, the Ministry of Environment ratified the “National Drinking Water Policy Framework” (World Bank, 2015). National Drinking Water Policy 2009 (Environment Department, Government of Pakistan, 2009) was followed by Punjab Drinking Water Policy 2011 (Government of Punjab, 2011) and the somewhat recent Punjab Municipal Water Act 2014 (Government of Punjab, 2014). While these are a step in the correct direction, the policies appear to have been created without the ground realities of Punjab’s complex situation in mind. This is where the fault lies.

To understand the current practice of water ‘management’ in urban centres of Punjab, one needs to visit the Punjab Local Government Ordinance 2001 (PLGO 2001) which was promulgated to devolve political power and to decentralize administrative control within the Punjab province. The Ordinance placed the responsibility for the provision of water supply and sewerage services with the Tehsil Municipal Administrations (TMAs) - a ‘Tehsil’ being a sub-district level administrative unit in Punjab. However, the ordinance did not place the burden of financing these services onto local governments.

A myriad of stakeholders and governmental agencies are part of the water landscape in Punjab’s urban centres. Most important being the Government of Punjab, represented by the Planning and Development Department, Housing Urban Development and Public Health Engineering Department (HUD&PHE), Development Authorities, TMA, WASAs; TMA staff as government employees, elected local government officials (Tehsil Nazims), council members, household customers, non-served households as well as commercial and industrial customers (although the share of industrial enterprises being served by public water supply is small), international financing agencies such as World Bank and Asian Development Bank, consumer groups and unions.

While TMAs remain administratively responsible for services such as water, sewerage and solid waste, it usually hands over the mandate to existing bodies such as waste management companies and Water and Sanitation Agencies (WASAs). Institutional mandate of service providers in large cities of Punjab is such that water and sewerage, drainage and solid waste. Functions are executed by three separate institutions within the city. In some cities like Lahore, Multan and Faisalabad independent solid waste companies have been formed. These companies collect, transport and dump solid waste in an organized way, usually to less detriment to water bodies (surface water) and aquafers (ground water). In other cities, however, solid waste is usually the function of a Solid Waste Directorate where its sweepers keep streets clean by dumping waste into drains. These drains are managed by the Town Municipal Administration (TMA). The TMA staff, given inadequate solid waste disposal facilities like landfill, sometimes keeps drains functional by pushing solid waste into sewers, which are the responsibility of WASAs (World Bank, 2015). Large open urban drains called “Nallahs” usually feed this untreated waste water into rivers or other water bodies leading to surface water contamination. These water bodies are, in turn, the responsibility of the Punjab Irrigation Department. Administrative stakeholders, therefor, are sometimes at loggerheads with each other, sometimes with roles overlapping e.g. the TMAs and local government provides the funds and sets the tariffs of services, whose delivery they have little or no control over. Authority and coverage is also ambiguous in areas whether the definition of ‘urban’ and ‘rural’ is unclear. This has led to certain areas of cities left without service (like solid waste collection and drinking water provision) altogether.

Apart from Lahore, Punjab’s other large eight cities i.e. Faisalabad, Gujranwala, Multan, Rawalpindi, Bahawalpur, Dera Ghazi Khan, Sargodha and Sialkot were studied by a German consultant in 2006. The findings, while interesting for outsiders, merely confirmed what insiders and practitioners had known all along. The report debated over issues of urban service delivery institutions and structures, legal provisions, reforms, inter- and intra-institutional alignment at the provincial and city levels as well as institutional and governance framework of urban service delivery institutions (data is usually not readily available and dependable, publicly-available reports have been few and far between. Fitchener, 2006 is a good example). Two of the most important findings were:

- The service providers are horizontally and vertically integrated organizations i.e. they are responsible for a particular service like water, sewerage and sanitation (horizontally integrated) and also vertically integrated from source to consumer and from consumer to final point of disposal. This gives them a wider prevue of each city’s needs;
- Non-Revenue Water (NRW) was identified as the priority area in the Punjab utilities by the five WASAs of Punjab (World Bank, 2015). The data collected from the WASAs on NRW revealed that WASAs were losing PKR 2.5 billion/year because the electricity bill for pumping water which was unbilled. The willingness-to-pay (WTP) and social surveys conducted by Government of Punjab showed end-users as generally unsatisfied with the quality of water and sanitation services, hence the reluctance to pay their bills.

Apart from the above, some key gaps identified by various reports over time (WAPDA, 2003; FODP, 2012) in the legal system surrounding urban water include a dearth of drinking water quality standards, monitoring and enforcement procedures; tariff making rules and guidelines; an unclear allocation of responsibilities; a dearth of effective performance monitoring mechanisms, blurred asset ownership and poor asset inventory keeping; and non-existence of effluent standards and water resource protection (including abstraction permits and control).

Table 1: Punjab Water and Sanitation Agencies Data

Description	**Unit**	**Faisalabad**	**Gujranwala**	**Lahore**	**Multan**	**Rawalpindi**
Population	million	3.1	1.7	6.2	1.8	1.3
Populated Served	million	1.55	0.54	5.5	1.2	1.17
Population Growth Rate	%	3.58	3	2.36	2.79	3
Water Supply						
Annual Production	million m^3	87.1	91.77	655	35.51	97.74
Total Length of Water Mains	km	1,487	372	5,400	1,280	1,250
Metered Customers	%	1	0	5	0	0
Water Service Connections						
Industrial	No	80	65	211	73	5
Commercial	No	2,583	1,245	39,187	2,892	8,864
Residential	No	114,260	24,781	586,891	58,371	104,32
Total	No	116,923	26,091	626,289	61,336	113,717

Source: WASAs and TMAs

The coverage of various water and sanitation agencies in Punjab can be seen in the Table below. It is worth noting that apart from Lahore, there are practically no metered connections in the other large eight cities of Punjab. Consumer connections are not metered and payments are made on a variety of scales. Some relate to property area, others to the size of the pipe supplying to the property. Illegal connections are widespread while service providers have limited powers and resources to tackle the problem effectively (see Fitchener, 2006).

Current Practice

Punjab benefits from one of the largest aquafers in the world as well as historically sufficient surface water through three rivers Chenab, Jhelum and Indus. The name '*Punj-aab*" itself means the land of five rivers. Historically the province profited from supplies from five rivers, two of which were later conceded to India through the transboundary Indus River Basin Treaty in the 1960s. Given this good fortune, Punjab has remained the most prosperous province of the country contributing to over 58% of the country's GDP, both through agriculture as well as industry.

However, with population growth, urbanization and a huge agricultural sector which utilizes irrigation water inefficiently, Punjab is now below the Falkenmark Water Stress Index. The Index's threshold value is 1000m3/capita/year. While Pakistan's overall Index is 1200m3, Punjab's has fallen to 910m3. Total water availability (surface and groundwater) is expected to come under further stress with the index expected to fall to 770m3 by 2025 (source: Punjab Irrigation Department). As meagre amounts of additional water can be expected in the system at any point in time, the situation is dire.

Punjab specifically and Pakistan in general is as high-risk area due to climate change. While glacial melting in the Himalayas due to global warming is expected to increase water in rivers over the next 50 years or so, this will lead to eventual reduction in flows. There is already an increased variation in rainfall patterns, with larger dry spells (such as those between years 2000-2007), and increased flooding and drought situations. It is expected that by 2070, surface water may see declines of 30-40%. While these scenarios need to be studied more scientifically, existing data does paint a grim picture for water-dependent Punjab. The province has also seen a continuous degradation of surface water and groundwater due to dumping, pollution, seepage, use of fertilizers in agriculture and untreated affluent disposal by industrial units. Water quality has especially degraded close to urban centres, which house half of Punjab's population. The level of degradation is so high that natural ecosystems do not have enough time to regenerate and provide ecosystem services historically provided.

Groundwater from the Indus aquafer has also been exploited excessively. According to the Department of Irrigation, one Million Acre Foot (MAF) of water was extracted in 1965. Since rainwater runoff allowed for a recharge of 43 MAF annually, a program was laid out to extract this amount through tube wells. This supplementary source of water was found extremely useful by farmers and the trend grew. Although public tube well development declined after the 1970s, private (unregulated) tube well development flourished. In 2000-1, there were 0.6 million private tube wells in Punjab. Water Sector Capacity Building and Advisory Services Project (WCAP) of the World Bank estimated the number to be 1.1 million in 2008-9. Because water extraction is unregulated, the amount of water extracted is also a guesstimate. However, there is a rapid lowering of the water table in the aquafer, especially around urban centres such as Lahore, which have been deemed critical. The Punjab Irrigation Department, which monitors groundwater levels estimates that the water table is being lowered by more than one foot a year in the Bari Doab areas.

On the city-level, water and related assets are owned by local governments. Although the Local Government and Community Development (LGCD) department may be construed to be the caretaker department for the assets. Assets are not registered, not their functionality and replacement monitored. In fact, most are not formally assigned to city governments for monitoring and control. No asset inventories or registers exist, neither are there comprehensive maps showing their location, date of construction, materials or current condition and serviceability. Information regarding assets is generally scant. There also seems to be no financial record-keeping for amortization and replacement purposes.

Fitchener (2006) found that water assets in Punjab were severely aging and that there were heavy limitations on operation and maintenance expenditures. Numerous assets, the study concluded, were in poor condition and are usually fully depreciated already or operating at minimal capacity due to age and wear and tear. The situation continues to date whereby outdated, depreciated assets continue to operate in a financially constrained environment. Due to the poor shape of assets, water losses from pipes, is estimated to be almost 60% of the supply in some cities (Fitchener, 2006). Typical water supply assets are deep-cased and screened tube wells fitted with turbines or pumps. These tube wells are frequently located within the vicinity of the area to be serviced. Water is extracted from the ground and distributed through groundwater pipes to end-users. There is no measurement of the volume of water extracted nor are consumers charged with the cost of extraction.

Not surprisingly, the problems faced are not only about extraction, assets or technology. The availability of the requisite technical and managerial skill set is also an issue. This is because of traditional human resource (HR) practices in the public sector. Performance, for example, does not have much influence on career advancement, thereby limiting the need for innovation or higher performance by staff. Also, recruitment bans are the norm, and staff planning and capacity building is unheard of. Commercial and customer service skills are neither developed not considered important. In fact, several water agencies struggle with technical staff numbers and capabilities such as operational skills as well. According to the Fitchener Report (2006), formal standards for service do not exist currently. Although variations between cities can be expected, quality is generally poor, with water agencies totally lacking the service mind-set.

Conclusions, Policy Options and Priorities

The situational analysis presented in the paper shows Pakistan's current practice to be manifestly unsustainable. Although reform is not a new concept and we have a series of policy initiatives taking place in Punjab in the form of policies and acts, the need for a much wider, more holistic reform is as urgent as the severity of water challenges constraining the country's growth potential and the liability of its cities. Other Asian cities that can proactively re-positioning themselves as live-able, economically viable and sustainable cities will be those that will plan and manage water resources in a more holistic and long-term way. It is these cities that will attract investors and stay healthy abodes for populations. Cities in Punjab must compete with these cities. To do so, several areas became apparent from the interviews conducted with several state actors including the addressing the poor state assets, improved service quality, policy adoption in practice, wider water and Environmental Management: better accountability, monetization of water and a far more robust regulatory environment.

Much of these proposed actions may be initiated in the short-term. However, large scale capacity building or the development of new, technically sound bodies to replace existing bodies would have to be undertaken. I concede that radically progressive, well-functioning planning and executing systems may not be possible immediately. Local governments differ from one city to another. However, given the severity and scale of the problem, action must be initiated somewhere. Private sector involvement for financing and best practice must not be ruled out. As policymakers work to renew the existing water management paradigms in the developing world, they need to recognize that water planning is one the most fundamental and important issue pertaining to their populations: one far more important that physical transport infrastructure (as has been the onus in Punjab). The prevalent system is not close to being prepared to support the country's economic growth. Punjab's lack of planning for water risks is aggravating unsustainable development, a declining quality of life and is ultimately undermining the economy.

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Aquaponic as a System of Building Integrated Food Production

Friederike Well[1]

[1] Technical University of Munich, Munich, Germany, friederike.well@posteo.de

Abstract: This paper describes the planning parameters to integrate an aquaponic system into a plus-energy house in Austin/Texas. The idea behind this is to close material cycles in the sense of Cradle to Cradle® and to consider existing waste as resources. Therefore, it was examined whether condensation water generated in air conditioning systems (fan coils) can be used to produce food in an aquaponic system. Aquaponics is a technology that combines fish farming and crop cultivation in a circulatory system. In this project, a new aquaponics concept of the Leibniz Institute of Freshwater Ecology and Inland Fisheries (IGB) is used, which provides individual water circuits for fish and plants, to allow the optimal conditions for fish farming and plant cultivation. The system is placed in a greenhouse. Tilapia were selected as suitable fish. Tomatoes and other crops grow in a “medium based” bed of 3,5 m^2 with a substrate of coconut fibre mats. Thus, about 75 kg of fish and 50 kg of vegetables are produced per year directly at the consumer's place of residence and in a nature-like circulation system.

Keywords: Aquaponic, Sustainable Building, Greenhouse, Water reuse.

Introduction

The impact of climate change calls for special protection of resources on Earth. Water is a particularly valuable resource, as it is the basis of life for man and nature. Reducing water consumption should therefore be targeted. An average American has a daily water consumption of 101.5 gallons (384 litres) in the household. Most of this is used for personal care. Approximately 70% of the water consumption takes place in interior spaces. 30% are used on the garden and outside (City of Philadelphia, 2017). In addition to this direct water consumption, the water footprint also shows the indirect (also known as virtual) water consumption caused by the production and transport of goods. This is where the USA has world’s largest. An average American citizen has an indirect water consumption of 2480 m^3 per year. This corresponds to 6,800 litres per day. In comparison, China has an average water footprint of 700 m^3 per capita per year (Hoekstra and Chapagain, 2006).

An integrated aquaponic system offers the possibility to reduce both, direct and indirect water consumption. The use of recycled water avoids additional water consumption from the public drinking water supply. The hydroponical cultivation method is twice as efficient in water consumption than conventional vegetable growing in the garden (Kloas et al., 2015). Furthermore, the water footprint of the inhabitants is reduced because the need for fresh food can partly be covered by self-cultivation. The world-wide average for 1 kg of tomatoes is 214 litres of virtual water (Matzke-Hajek and Vereinigung Deutscher Gewässerschutz, 2011). This consumption can be reduced by local cultivation and the use of recycled waste water.

NexusHaus

The NexusHaus was developed as a contribution to the international competition "Solar Decathlon 2015" by a team of the University of Texas at Austin and the Technical University Munich. It was planned and modified for three locations: Austin/Texas, Irvine/California and Munich/Germany. This paper focuses on the location in Texas. The aim was to create a plus energy house based on three principles according to the Cradle to Cradle® philosophy: Waste equals food, use current solar income and celebrate diversity (Salfner et al., 2017). The sustainable use of water was a key element in the planning process. The building is based on a modular concept, which can be enlarged for households with many people. In this work, the basic variant of the NexusHaus, which consists of two building parts, a day and a night module, with a connecting terrace, is adapted (Fig. 1).

Figure 1. NexusHaus Floor Plan.

Aquaponics

Aquaponics is a technology for food production, which makes use of the symbiosis of natural material cycles. It combines recirculating aquaculture (fish production) with hydroponics (plant cultivation without soil) by nitrification. The excrements of the fish (ammonium and ammonia) must be removed from the water. Like it is shown in Fig. 2 aquaponics converts these substances by means of bacteria into nitrates, which are then used as plant fertilizers. By absorbing the nutrients, the water is filtered and can be returned to the fish (Blidariu and Grozea, 2011).

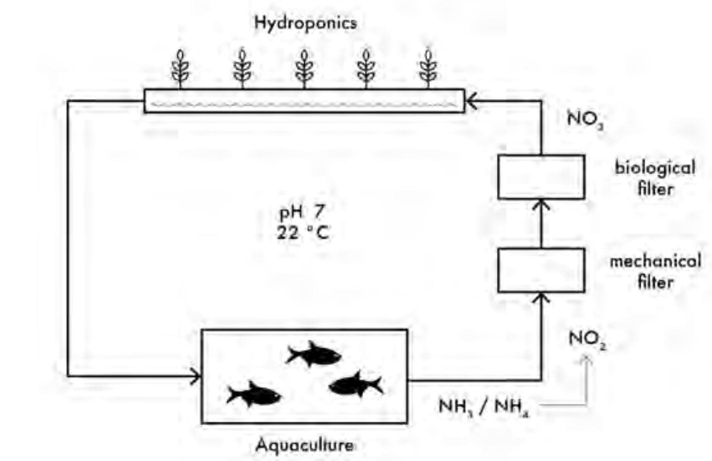

Figure 2. Function of a single circuit aquaponic system.

Aquaponics considerably reduces the water consumption for fish production and plant cultivation. In the research project ASTAF-PRO, 1 kg of fish (tilapia) and 1.67 kg of tomatoes were produced on average with 220.6 litres of fresh water in a testing period of nine months. Compared to a conventional recirculating aquaculture this requires less than ⅓ of the water consumption (Kloas et al., 2015). ASTAF-PRO employed a special technique in which the aquaculture and hydroponics circuits were decoupled and the water quality was regulated separately for plants and fish. (Fig. 3). As a result, both systems could be optimized to meet their needs in particular with respect to the pH value.

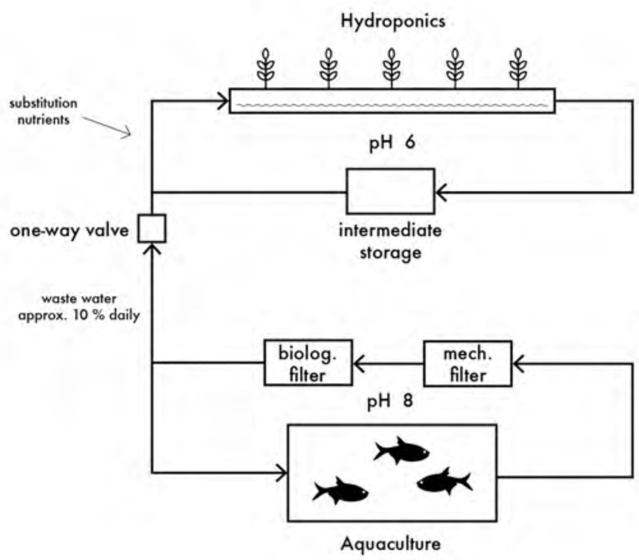

Figure 3. Function of a decoupled aquaponic system.

Since aquaponics works independently of soil conditions and can be adapted to many climatic conditions, it plays an increasing role in the question of food security and food production in water-poor areas. In 2012 the Food and Agriculture Organization of the United Nations (FAO) supported 15 families in the Gaza Strip with small aquaponics units to enable them to produce food independently in backyards and on rooftops (Somerville and Ferrand, 2013). A third project, which is referred to is the aquaponics facility of the “Arche Noah” in Menden, Germany. It is a medium-sized project that has been designed to be particularly energy-efficient in middle latitudes. The three systems are compared in Table 1.

Materials and Methods

To determine the integration of an aquaponic system into a single-family home, several aquaponic systems were first analysed and tested for compatibility (Table 1). The projects showed marked differences in their objectives. The ASTAF-PRO project at the IGB Berlin (also known as "tomato fish") is, for example, a research project that focuses on a larger scale for industrial production. Therefore, a profitable workflow is an important goal.

Table 1. Comparison of listed aquaponic systems

Name and location of aquaponics	Type of system	Size of the fish tank / growing area	Hydroponic system	Type of fish	Type of plants
ASTAF-PRO, Berlin	Decoupled	10 m^3/ 116 tomato plants	NFT (nutrient film technique)	Tilapia	Tomatoes
FAO, Gaza	Single circuit	1 m^3/ 4 m^2	Media based (volcanic gravel)	Tilapia	Mixed
Arche Noah, Menden	Single circuit	2 m^3/ 2 m^2	Media based (gravel)	Tilapia/ carp	Mixed

The FAO project focuses on autonomous food supply in politically troubled areas. Although a small scale is foreseen, the aquaponic system has been designed for other climatic conditions and is, therefore, only to a limited extent comparable to the NexusHaus. Also, the aquaponic project of the “Arche Noah” in Menden has a small scale. However, the focus is on teaching children in context of environmental education. Another goal is sustainability and energy-efficient operation.

Based on an analysis of the presented systems, key parameters for an aquaponic system, which can be integrated into the NexusHaus, have been defined: Use of recycled water as resource so that no additional consumption of fresh water from the public utility network is needed. Energy-efficient operation throughout the year and a user-friendly handling and care, that doesn’t require expert knowledge.

Water

The aquaponic system is to be supplied exclusively with water, which is produced in the house as a "waste product". The first consideration was to use the condensation of the fan coils. To determine the suitability of this option, the water quantity must first be determined. It is known that when cooling, the interior air forms condensation water because warmer air can absorb more moisture than cold air. For this reason, air conditioning systems have a line to the sewage system of the building. However, the respective amount of condensed water is dependent on numerous components like absolute humidity, relative humidity and air temperatures. In case of the fan coils, only the interior air is cooled and there is no fresh air supply (Daniels, 1996). For this reason, the accumulating humidity only results from the perspiration of the bodies of the inhabitants and their activities in the house.

It is assumed that a person exhales an average of 50 - 150 g of water per hour depending on their activity. In addition, moisture is released to the air when showering, cooking and drying. Therefore, according to a rough estimate it is assumed that three litres of moisture are released to the interior air per inhabitant daily (Baunetz Wissen, 2017). This value, however, fluctuates strongly and is in a great extent dependent on the presence of the inhabitants.

The quality of the condensed water is suitable for aquaponics. The pH is in the neutral range, which corresponds to the requirements. In addition, the pH in the system must be checked and adjusted again and again, to not harm the fish. Although the condensed water of the fan coils can be used in aquaponics, this option is not recommended. The reasons for this are mainly the high effort compared to a very strongly fluctuating and rather low gain. Since the required amount of condensation water cannot be guaranteed with certainty, but an aquaponic system needs fresh water every day, two other options for water extraction from existing resources (rainwater and greywater) will be examined in more detail below.

For the NexusHaus it is planned to catch the rainwater. However, the water thus obtained is intended for the thermal storage tank and is therefore not available for aquaponics (Salfner et al., 2017). In principle, rainwater is very suitable for aquaponics. The EU-funded research project INAPRO, developed based on ASTAF-PRO, aims to cover the fresh water demand completely through the collection of rainwater (Kloas et al., 2015).

The third possibility is the use of greywater. In the NexusHaus the domestic separation of blackwater and greywater is planned. Greywater is waste water from the shower, the bathroom sink and the washing machine that is free from faeces. On average about 163 litres can be collected daily, which are not directed into the public sewage system, but are treated directly in the house for reuse (Salfner et al., 2017). If the demand for toilet flushing and washing machine are removed, a daily average of 120 litres remains, which could be utilised to the aquaponics. In this case as well, the water quality must be monitored and adjusted if necessary.

An aquaponic facility needs about 10% of the water volume of fresh water every day. This value can be reduced even further with well-balanced and monitored system. ASTAF-PRO provides, for example, 3-5% water requirement per day (Kloas et al., 2015). When using recycled greywater, the required amount of water would be reliably available and it would also be possible to tide over several days if the inhabitants were not present.

Location

For an integration of aquaponics into the NexusHaus, it must be decided where the system is to be placed on the site. Various possibilities are conceivable. A placement within the thermal envelope has the advantage of constant temperatures. Nevertheless, this option is discarded because the humidity should be higher for plant cultivation than it is in most dwellings and fish odours of aquaculture could disturb the well-being of the inhabitants. In addition, there is a greater need for artificial lighting to ensure good plant growth and the housing space of the NexusHaus has been narrowly dimensioned.

An open-air planting is also feasible. In this case, however, control of the temperatures becomes more difficult. In addition, the rain shelter of a greenhouse counteracts a pest infestation (tomato late blight) (Meyer-Rebentisch, 2017).

After weighing up these aspects, the decision was made to stay on the south side of the day module, as originally planned in the NexusHaus (Fig. 1). In contrast to the competition design, the system is placed in a greenhouse, which also houses the fish tank. In the combined placement of fish and plants, a favourable metabolism takes place. The plants convert the CO_2 released by the fish into oxygen (Kloas et al., 2015). The area between the ramp and the house wall offers enough space for a small aquaponic unit on an area of about 6 m².

Fish

The selection of suitable fish for aquaculture should be made regarding regional conditions. The corresponding comparison factors of three fish species are listed in Table 2. Tilapia are particularly suitable due to their uncomplicated housing conditions and have proved themselves as "standard fish" for aquaponics. However, other species are also possible. In Central Europe, where temperatures are lower than in Texas, carp and trout would be an option. The carp, because it is very resistant even at cold temperatures. The trout, because it is a very popular food fish. Trout is excluded because it gets along very badly with water temperatures above 20 ° C (Würtz, 2017). According to the food preferences in the US, the African catfish is considered as an option for the location in Austin/Texas.

Table 2. Different fish species for aquaponics



	Nile tilapia *(Orechromis niloticus)*	Common carp *(Cyprinus carpio)*	African catfish *(Clarias gariepinus)*
Temperatures	14-36 °C (optimal 27-30 °C)	4-34 °C (optimal 25-30 °C)	5-34 °C (optimal 24-30 °C)
Stocking density	60-150 kg/m³	10 kg/m³	max. 350 kg/m³
Oxygen content	With oxygen supply higher feed conversion ratio	No supply necessary	Tolerates little oxygen
Consumption	Versatile food fish	Many bones, very fat, only moderately popular	Versatile, very popular in America

For the NexusHaus tilapia are selected as suitable aquaculture fish. Due to the low demands regarding the housing conditions, their tolerance to high water temperatures, which are to be expected in the summer and the proven suitability for aquaponics, they are most likely to be used for year-round operation. If favoured by the inhabitants, carp or catfish can be used as an alternative. For these two species, there is less quantified experience in aquaponics, though.

Plants

For the inhabitants of the NexusHaus, the handling and the use are particularly important in the selection of the plants. For this reason, a "media-based bed" should be chosen, in which different plants can be cultivated. The substrate used are coconut fiber mats, which must be exchanged more frequently than mineral substrates, but are compostable in the sense of Cradle to Cradle® (Somerville et al., 2014). It would be ideal to find a regionally available organic raw material, which can serve as a substrate.

For the planting mainly tomatoes are used, as well as herbs and lettuce. With these plants, the design and calculation of the aquaponic system is made. However, plants can be replaced at pleasure (for example, cucumber and pepper instead of some tomato plants).

Results

In order to achieve higher yields and improve the stability of the system, the decision was based on a two-circuit system. The first circuit contains a recirculating aquaculture with tilapia and is connected via a one-way valve to the second circuit, which contains hydroponics. The entire system is housed in a greenhouse that can be shaded and additionally has air conditioning to compensate for the high temperatures that prevail during the summer months in Texas.

The fish tank holds a volume of 500 liters. It contains 35 kg of fish which is graded in different sizes. Large fish are regularly removed and smaller ones are added so that the stocking density is always in the ideal range of 60-150 kg / m³. Figure 4 shows the arrangement of the aquaponic elements. Above the fish tanks are the beds located. The waste water from the fish tank is cleaned from solids in the mechanical filter and nitrated in the biological filter. The water then flows through the one-way valve into the sump, where missing nutrients are added and pH is adjusted. The water is pumped to the beds where strong starters like tomatoes, peppers and cucumbers are grown. Lettuce and herbs can always be added in the beds because they are less nutrient-needy.

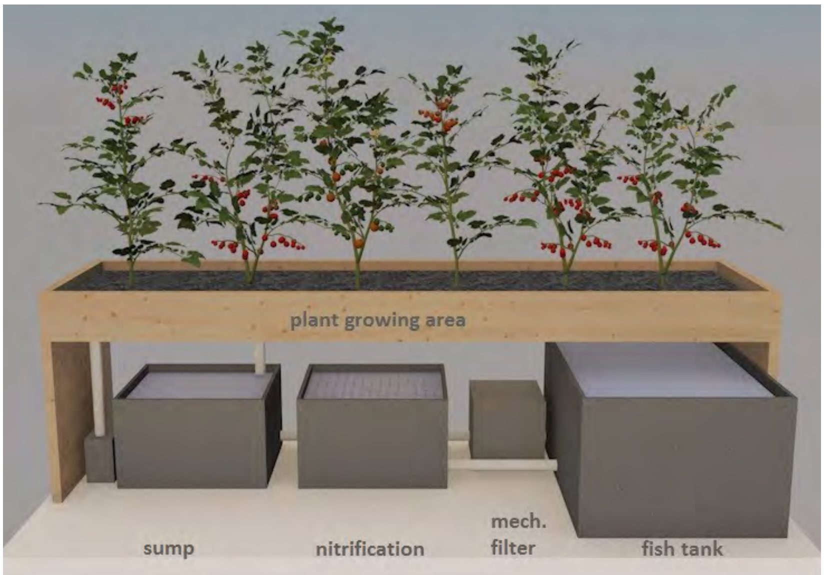

Figure 4. Design of the NexusHaus aquaponic unit.

The fish tank is insulated to compensate for large temperature fluctuations. In winter, night temperatures in Texas can approach the freezing point, which is why a heat exchanger is installed for heating and cooling. It is connected to the thermal storage of the house. The presented aquaponic produces about 75 kg fish per year and 50 kg of tomatoes or other vegetables in a growing season of eight months.

Discussion

When integrating an aquaponic system into a single-family house, it must be clarified whether the system can still be assessed as "sustainable". It is remarkable that a high energy expenditure is necessary in order to keep all parameters in equilibrium. For example, heating energy must be applied in winter and cooling energy in summer. In addition, investment costs are relatively high for a small plant. In the case of a larger installation, these critical points are significantly reduced. However, if it is possible to cover the energy expenditure from self-generated renewable energies and the investment costs are taken into account, the question arises as to how the system is pleasant to use for its users. Basically, aquaponics is only to be used after thorough instruction. A good understanding of fish farming and plant rearing is important to avoid mistakes. The system requires a lot of maintenance. Despite feeding equipment and automated operation, a daily inspection is urgently recommended. The quality of water must be checked regularly, which in the ideal case could be transmitted via sondes that send digital readings to the residents' smartphone.

The presented results could not be practically tested. This would be necessary, in particular, to determine the climatic conditions in the small greenhouse more precisely, thereby quantifying the energy expenditure.

Conclusions

It is possible to integrate an aquaponic system into the NexusHaus and to reuse water that is generated as a waste product. The fresh water supply with treated greywater is favored because the required amount is constantly available. The system is to be housed in a greenhouse on the south side of the day module. It contains a 500 litre tank, which is used to cultivate tilapia with 35 kg biomass all year round. The hydroponic plant cultivation is to take place from April to October in a media-based grow bed in which coconut fiber matts serve as substrate. A heat pump to the thermal storage of the NexusHaus keeps the temperature in the fish tank constant. The yields of 75 kg of fish and 50 kg of tomatoes per year would lower the needs of the residents for external food supplies and thus have a positive impact on the water footprint.

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Potential cooling energy reduction by a wind tower model in Milan and Rome climate

Mehrnoosh Ahmadi[1] and Mario Grosso[1]

[1] Department of Architecture and Design, Polytechnic University of Turin, Turin, Italy.

Abstract: The human-induced emission of greenhouse gasses has largely contributed in the current quickly proceeding earth warming. The building sector represents 19% of all global GHG emissions and one-third of CO2 release, most of which are indirectly coming from the electricity consumption in buildings. The inevitable increase of cooling energy demand due to global warming, improving life standards and population growth associates with a higher electricity consumption and more CO2 emission. Therefore, implementation of passive ventilation and cooling strategies as an alternative solution for providing human comfort becomes of vital importance in saving of building energy and hence contributes in climate change mitigation set by United Nations Environment Programme (UNEP). One of the ventilative cooling components that despite its antiquity has only lately attracted attention of sustainable designers and engineers is the Iranian wind tower. A previous parametrical analysis of a wind tower model using SPERAVent—a simplified thermal simulation tool for calculating the potential cooling energy reduction due to controlled natural ventilation—showed promising results in Palermo climate conditions. In this paper, a similar assessment has been done using Milan and Rome weather data and the possible application of wind towers in different climatic zones has been investigated.

Keywords: ventilative cooling, wind tower, SPERAVent, cooling energy reduction, controlled natural ventilation

Introduction

Statistics show that from 32.4 PWh final energy used in the world in 2010, 32% was in the building sector (24% in residential and 8% in commercial) (Lucon et al, 2014). IEA suggests that the energy use in this sector continues to grow at an average rate of 1% per year with households accounting for about 60% of the increase in energy demand, majorly in form of electricity (IEA, 2013). Furthermore, in the same year, the building sector's emissions of greenhouse gases (GHG) represented 19% of all global GHG emissions and about one-third of the CO_2 emissions, indirectly coming from the electricity consumption (Lucon et al, 2014). In fact, the associated indirect CO_2 emissions, at 5.6 Gt, are almost twice as large as the direct emissions in the buildings sector itself (IEA, 2016). Inevitably, part of the climate change mitigation policies set by United Nations Environment Programme (UNEP) is to impose new or higher energy performance standards in buildings for lighting, heating and cooling appliances (IEA, 2013).

Space cooling currently accounts for an estimated 5% of total final energy consumption in buildings and as the ETP models estimates, it is the fastest growing end use in this sector (IEA EGRD, 2016) partly due to global warming and further because of the improving life standards and cost-effectiveness of air-conditioning appliances for increasing number of population (Kamal, 2012). In fact, IPCC estimates that the global demand for residential air conditioning alone will rise from 300 TWh per year in the year 2000 to 4.000 TWh in 2050 and 10.000 TWh by 2100, with the majority of growth in developing countries. About 75% of this increase is due to rise of income in emerging market countries and 25% is due to climate change (Arent et al, 2014).

Among all technological options for reducing cooling demand, ventilative cooling represents an attractive energy efficient passive solution for cooling and overheating prevention (IEA EGRD, 2016). One of the ventilative cooling components that has attracted the attention of sustainable designers and engineers is the antique Iranian wind tower a.k.a. Badgir which was commonly employed in traditional climatic architecture of desert cities of Iran. In hot arid regions of Middle East, where cities were formed compactly to hinder sand storms and excessive sunshine from reaching a human level (Ghobadian, 2008), wind towers were constructed in order to convey the cooler, fresher and cleaner wind of a higher altitude into the buildings. Also, their role in maintaining a constant airflow in public cisterns was crucial in preventing any dew or humidity from forming inside the cistern (Memarian, 1993).

Literature review

Wind towers perform under two conditions. When there is wind, the distribution of positive and negative pressure coefficients around various mouths of wind tower and other building apertures will create an airflow from the positive pressure openings to the negative ones. Instead, when there is no wind, often at night, the solar radiation heat, stored in the tower during the day, releases into the tower and creates a stack effect which results in an airflow into the buildings through the windows (Bahadori et al, 2014).

A CFD analysis of a model _a room and a commercial wind tower on roof top_ compares the effect of wind and buoyancy. In case the ventilation only relies on the tower and there is no other opening in the room, the airflow is mainly wind-driven and the buoyancy effect is negligible. Instead, adding a window on the leeward side of the room will provide 47% more airflow (Hughes et al, 2011).

Other studies focusing on geometrical elements of the wind tower show how the height of the tower, its section shape and measurements and its internal divisions can affect the temperature and mass flowrate of the air entering the building (Bahadori et al, 2014).

CFD and wind tunnel test with smoke visualisation show that increasing the number of openings of the tower decreases its sensitivity against wind angle, while the natural ventilation performance of those with fewer openings drops more considerably when the wind angle increases (Montazeri, 2010).

Another CFD analysis shows how a rectangular wind tower has a better efficiency than a cylindrical one due to its sharp edges that create a greater flow separation and higher pressure differences across the tower (Elmualim et al, 2002).

A smoke visualisation test proves that in one-sided wind towers, for an approaching air velocity of 10 m/s, inclined- and curved-roof towers have 7% and 15% more entering flow rate respectively (Kazemi et al, 2012).

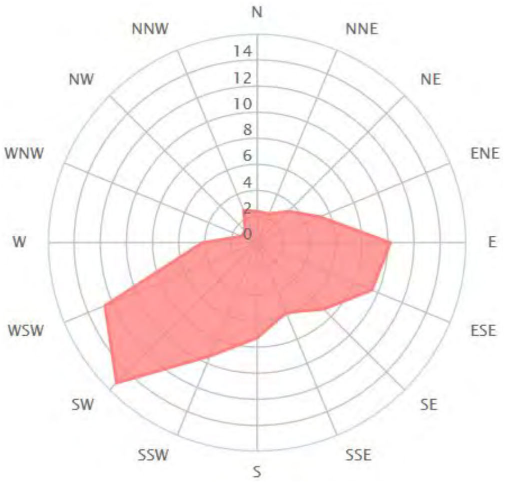
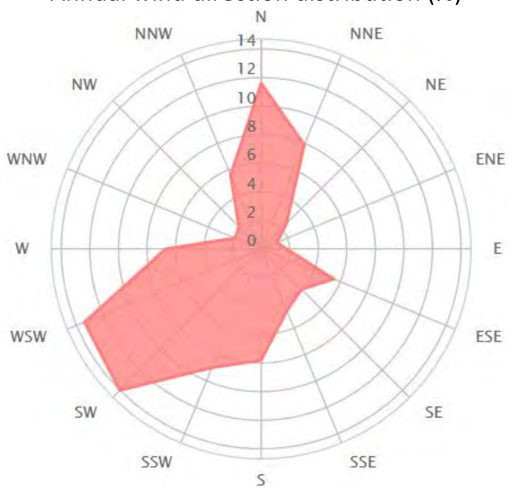
Assessment of potential cooling energy reduction by a wind tower model using SPERAVent

SPERAVent is a simplified dynamic thermal simulation tool for evaluating the hourly energy behaviour of a building consisting of no more than two thermal zones, during the cooling period (Grosso et al, 2011). This program has been utilised previously for a parametrical analysis of a conceptual model comprising a one-channel wind tower and a room in Southern Italy –Palermo– climate and has shown a saving of between 43% and 61% in annual cooling demand (Grosso et al, 2016). In this paper, the same model has been assessed considering Milan and Rome climatic conditions.

Climate of Rome and Milan

The climatic characteristics of Milan and Rome are summarized in the following table (windfinder.com, n.d.) (climatemps.com, n.d.).

Table 1. Comparison between Milan and Rome climatic conditions.

Milan	Rome
45°26'N, 9°16'E, 103 m	41°57'N, 12°30'E, 24 m
Humid subtropical climate (Köppen-Geiger classification: Cfa)	Hot Mediterranean, subtropical climate (Köppen-Geiger classification: Csa)
The annual average temperature is 12.5 °C	The annual average temperature is 15.1 °C
The warmest month is July with mean temperature of 23.1 °C	The warmest month is July with mean temperature of 23.95 °C
The coolest month is January with mean temperature of 1.35 °C	The coolest month is January with mean temperature of 7 °C
Average annual precipitation is 943.2 mm	Average annual precipitation is 837.3 mm
Annual wind direction distribution (%) 	Annual wind direction distribution (%) 

The model characteristics

The model (Figure 1) chosen for the assessment comprises of a one-story square room with an area of 25 m^2 and a height of 3 meters and an 8-meter high wind tower with a square cross section and a surface area of 2.25 m^2 which makes the volume of the whole model 91.875 m^3.

The specific thermal capacity of room and tower is rather close as the finishing materials for both calculated units are similar. Mortar is selected for external finishing, plaster for internal one and wood for the flooring. The thermal bridge is thought to have a 5% adverse effect in dispersion of energy between internal and external environment. As part of this assumption, walls are supposed to have exterior insulation coating without any overhangs or balconies.

In the first set of assessments (orientation effect), all the opaque surfaces including walls, ceilings and floors, of both room and wind tower are thought to be identical as a matter of thermal energy transmittance. They are all considered medium weight with no/external insulation having rough light-colour surfaces. Therefore, their heat capacity is 155 kJ/m^2K and their thermal transmittance is 0.3 W/m^2K. In the second assessment, the effect of different heat capacities of opaque surfaces on cooling energy reduction has been studied.

The tower has openings on all four sides, one of which is alternatively opened during the simulation. Similarly, the room has windows on three sides of it and an outlet opening in place of its intersection with the tower. All eight apertures are identical in terms of dimension, each having an area of 1 m^2. The tower's openings have their barycentre at 7 meter and the room openings have theirs at 1.5 meter form ground level.

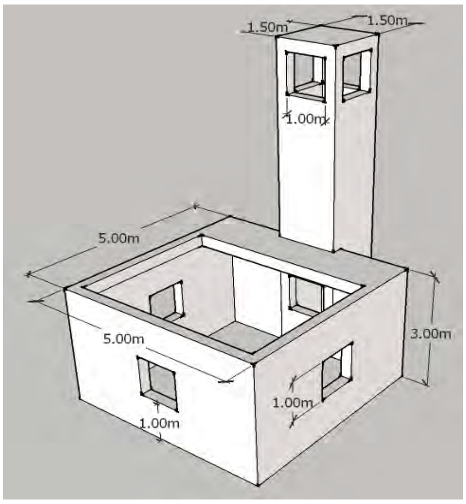


Figure 1. The model of the room and tower assessed in SPERAVent.

All these transparent surfaces have matching thermal characteristics such as 1.2 W/m^2K for thermal transmittance, 0.5 for solar factor, 0.8 for frame factor and 0.5 for shading factor of mobile screens.

The mechanical ventilation is absent and the infiltration is assumed a minimum of 0.5 vol/h. The apertures operate automatically in function of air temperature. The airflow direction _from wind tower's openings to room's apertures or vice versa_ depends on the pressure difference, i.e. on air temperature difference and wind force combined, between inlet and outlet openings. For the purpose of this calculation, no external obstruction to wind is considered.

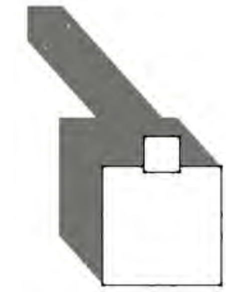
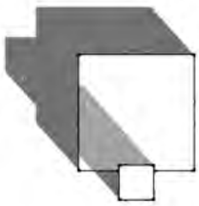
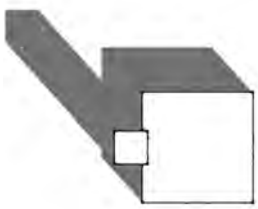
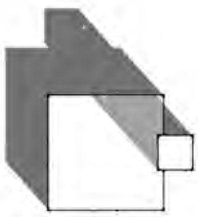
Assessment of orientation

In the first set of simulations, the model's orientation and its relevant exposure of apertures were studied by alternatively opening one of four tower apertures, one of three room windows and rotating the model along four main geographical axis. The following table summarises the 48 combinations.

According to Table 2, the optimum orientation for both Milan and Rome is when the tower is located in southern side of the room and the open apertures are the northern window of the room and the southern opening of the tower.

Table 2. Effect of orientation (model layout, direction of tower's opening and room window aperture) on energy saving percentage. (* highest energy saving, ** lowest energy saving)

Model layout	Direction of tower aperture	Direction of room aperture	Number of airflow deviations	Energy saving percentage Milan	Energy saving percentage Rome
	W	E	3	85.92	62.09
	W	S	2	91.81	67.62
	W	W	3	80.54**	50.36

	N	E	3	85.51	58.73
	N	S	2	90.57	64.41
	N	W	3	85.83	61.18
	E	W	3	87.03	61.91
	E	E	3	80.54**	50.36
	E	S	2	92.07	68.81
	S	S	2	89.47	59.68
	S	E	3	87.49	64.25
	S	W	3	87.39	62.36
	S	W	3	88.21	62.21
	S	E	3	88.29	64.14
	S	N	2	93.15*	69.81*
	E	N	2	92.85	67.3
	E	W	3	87.92	61.72
	E	E	3	81.64	49.95**
	N	E	3	86.41	58.5
	N	W	3	86.71	60.98
	N	N	2	90.08	59.47
	W	N	2	92.31	68.26
	W	E	3	86.85	61.94
	W	W	3	81.64	49.95**
	W	E	2	92.13	67.51
	W	N	3	87.39	62.87
	W	S	3	87.43	62.34
	N	S	3	85.25	58.99
	N	N	3	81.54	50.27
	N	E	2	91.86	65.18
	S	E	2	92.98	69.3
	S	N	3	88.15	64.74
	S	S	3	81.54	50.27
	E	S	3	87.99	64.14
	E	N	3	88.06	61.89
	E	E	2	90.05	59.69
	E	W	2	92.78	67.08
	E	N	3	88.12	61.89
	E	S	3	88.07	64.17
	N	S	3	85.32	58.96
	N	N	3	81.63	50.27
	N	W	2	92.16	66.19
	S	W	2	93.03	67.74
	S	N	3	88.24	64.74
	S	S	3	81.63	50.27
	W	S	3	87.52	62.34
	W	N	3	87.51	62.87
	W	W	2	90.14	59.68

Depending on the direction of the openings, the airflow is subject to a number of deviations. As reported in Table 2, for each model orientation, when there are fewer deviations, the energy saving is higher. The worst cases are those where the inlet and outlet apertures face the same direction and thus the outlet air by stack effect faces the incoming wind.

Table 3 and 4 summarise the cooling demand for the two cities in five warmer months of the year, the sum of which makes the net annual cooling demand in Milan's optimum case to reduce from 1015.69 kWh/year to 69.60 kWh/year by means of controlled natural ventilation (CNV). In best case of Rome, these numbers are 2040.82 kWh/year and 616.09 kWh/year respectively.

Table 3. Monthly cooling demand (kWh/month) in absence and presence of CNV system for Milan.

	May	June	July	August	September
Presence of CNV	0.0	0.73	26.97	38.6	3.3
Absence of CNV	0.0	132.15	413.44	334.18	135.92

Table 3. Monthly cooling demand (kWh/month) in absence and presence of CNV system for Rome.

	May	June	July	August	September
Presence of CNV	0.0	16.2	173.08	327.36	99.46
Absence of CNV	17.11	266.93	668.33	761.97	305.9

Assessment of internal heat capacity

For this part of the assessment, the best performing orientation has been selected as the reference where for both Milan and Rome the main orientation was north, and the openings were facing south on the tower and north on the room. In the previous assessment with medium-weight opaque elements (walls, floor and ceiling) corresponding to an internal heat capacity (IHC) of 155 kJ/m^{2}K and thermal transmittance of 0.3 W/m^{2}K, the cooling energy reduction were 93.15% and 69.81% for Milan and Rome respectively.

Table 4. Effect of heat capacity of opaque surfaces on cooling energy requirement and reduction.

Internal heat capacity (kJ/m^{2}K)	Milan: Net cooling requirement (kWh/year) Without CNV	Milan: Net cooling requirement (kWh/year) With CNV	Milan: Energy reduction (%)	Rome: Net cooling requirement (kWh/year) Without CNV	Rome: Net cooling requirement (kWh/year) With CNV	Rome: Energy reduction (%)
85	1069.04	153.22	85.67	2108.01	741.54	64.82
155	1015.69	69.60	93.15	2040.82	616.09	69.81
225	985.96	36.86	96.26	2004.19	557.02	72.21

Considering light-weight elements with an IHC of 85 kJ/m^{2}K and the same thermal transmittance of 0.3 W/m^{2}K, the cooling demand reduction would become 85.67% in Milan and 64.82% in Rome. Whereas, using heavy weight elements with 225 kJ/m^{2}K of IHC and equal thermal transmittance, would increase the reduction percentage to 96.26% and 72.21% for the two cities correspondingly.

Obviously, any increase in the heat capacity of the walls, would decrease the cooling energy requirement of the whole model, as shown in Table 4 –net cooling requirement. However, in presence of a controlled natural ventilation (CNV) system, the decline is greater and consequently the energy reduction percentage is higher in case of a model with higher thermal mass value.

Conclusion

A conceptual model of a one-sided wind tower and a room has been assessed in SPERAVent software for Milan and Rome with humid subtropical (Cfa) and hot-summer Mediterranean (Csa) climatic conditions and has shown circa 93% and 70%, respectively, of saving in cooling demand, as a maximum. Further theoretical and experimental investigations are needed in order to evaluate the applicability of a wind tower system in the whole European territory.

Based on statistical studies for the Mediterranean area (Chiesa et al, 2015) and Central and Southern Europe (Grosso et al, 2015), it is already possible to estimate the European zones which have the highest potential of applying a controlled natural ventilation technique as a function of wind force. In these zones, the application of a wind-tower system in new building projects should be easy, being mainly a matter of applying the correct knowledge and methodology in the design process. More difficulties might be found in retrofit projects, where orientation of buildings and openings, which were found to be in the present study the parameters most affecting the energy performance, are very much constrained by the site context.

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Design to Thrive

Evaluation of the performance of an innovative glazing system by a comparative experimental analysis

Beatriz Arranz[1], Sergio Vega[2], Cesar Bedoya[2]

[1] Instituto de Ciencias de la Construcción Eduardo Torrroja (CSIC), Madrid,Spain
beatriz.arranz@ietcc.csic.es

[2] UNiversidad Politecnica de Madrid, Madrid, Spain

Abstract: A difficulty in establishing to what extent innovative windows are efficient is observed, therefore, there is a need to generate an experimental methodology for performing the analysis of the systems. First, the design and construction of an innovative glazing system is carried out, whose performance will be evaluated. The design criteria of this prototype are to optimize the use and storage of passive solar gain. The evaluation of the performance of the system is carried out by means of an experimental comparative analysis between the system and a standard element. To carry out this analysis, two equal experimental cells have been designed and constructed, where a constant internal temperature is maintained, supported by a heat pump. These cells have been monitored during nine months, obtaining consumption, temperature, and relative humidity data. Savings on consumption of heating in winter are up to 48% during a high radiation winter day. The objective of harnessing solar radiation is reached and is reflected in monthly reduction consumption up to 25% on heating in the cold months without penalizing cooling consumption in summer. Performance of the active glazing panel is confirmed to be optimal according to the design strategies for the climate of Madrid.

Keywords: windows, glazing, energy efficiency, experimental cells.

Introduction

Buildings and their environment are responsible for 40% (Enerdata, 2012) of the overall energy consumption in European countries. It has been identified as the sector with the largest energy saving potential (circa 75%) (Ristori, 2013). The reduction of energy demand on buildings, especially taking advantage of passive solar gain wasted so far, is one of the greatest challenges to achieve the objectives of H2020 strategy related to CO2 emissions, energy demand, and the share of renewable energy (EEFIG,2015) within this sector.

Energy Efficiency is one of the greatest energy resources, considering the potential effect over energy dependency from external countries. Within the European Union, four main directives have been developed to set the roadmap for the built environment, towards the objectives to reach by 2050: (EU,2002): Energy Performance in Buildings (EPBD), (EU,2009): Use of renewable energy, (EU,2010): Net-Zero Emissions Buildings, and (EU,2012): New directive for Energy Efficiency in Buildings.

In Spain, IDAE data (1) indicates that between 25% and 30% of our heating needs are due to the heat losses that arise through windows.

Regarding energy consumption associated with windows, several studies indicate their high potential for savings (Avasoo et al, 2004) *"The energy saving potential in the CPIV-FIZ studies, only by upgrading glass U-values from 5,7 and 2,9 to1,6W/m2K could save 1,115*

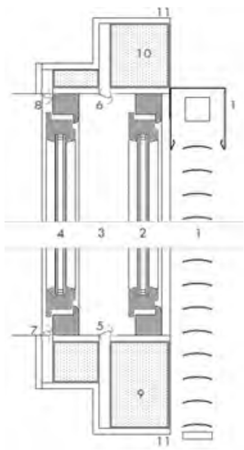
MGJ (million gigajoules or 26 million Toe (Tonnes of oil equivalent)each year. The CO2 reduction was estimated to 82 million tonnes per year.”

The INVISO (Industrialized sustainable Housing) Project aimed to develop a new industrialized, light, sustainable and energy efficiency construction system. It should be a competitive system especially focused on its effect on energy savings and associated GHG emissions. (Vega, S. et al, 2011).

The system designed is a combination of 3D and 2D modules; shown in figure 2. The SD10 prototype, presented in figure 3, is a basic unit of the INVISO system, built at the UPM Campus in Madrid.

Figure 1. On the left INVISO industrialized construction system Project. On the right unit Prototype SD10.

In this context the active modular glazing panel has been designed, which is a 2D glazing module for the south façade.



1. Solar Device
2. Exterior window
3. Air gap
4. Interior window
5. Chamber inferior grid
6. Chamber superior grid
7. Interior inferior grid
8. Interior superior grid
9. Inferior Heat Exchanger
10. Superior Heat Exchanger
11. Structural Frame

Figure 2. Active modular glazing panel components.

The system integrates a doble galzing area, a heat exchanger and a solar control devise. The active elements are controlled according to the user needs and the exterior climate conditions. Components of the system are shown in figure 2: double window with an intermediate air chamber, an exterior sun protection, two heat exchangers composed of PCM (phase change material, Rubitherm 21ºC) and four air renovation grids. The sun protection and the grids will operate, allowing the movement of the air through the chamber and through the heat exchangers and allowing or blocking the access of solar radiation.

The air is pre-heated or pre-cooled by passing heat exchangers before accessing the dwelling; In addition, these exchangers absorb the energy that is released later reducing the air conditioning needs of the building.

Establishing to what extent this innovative glazing system is efficient is the objective of this work; therefore, an experimental research for performing the analysis of the efficiency has been carried out.

Methodology

The active modular glazing panel is designed and built for experimental prototype SD10. However, a difficulty to isolate the effect of the system to establish to what extent it is efficient is observed, therefore, a sample is built to be comparatively evaluated to a conventional window in two experimental cells where the variables and its effects are isolated.

In order to carry out this analysis, two identical adiabatic spaces (cells) have been designed and built; on south façades the prototype and the reference windows are placed, being the only surfaces with a significant heat transfer.

Cell 1 will be the space in which the innovative system (Prototype) is placed, and in cell 2, the reference window is placed. In these spaces a constant interior temperature is maintained with the support of a heat pump and the consumption of air conditioning is counted. Measurement was carried out during a period of 9 months, from July to March, analyzing and comparing the results, thus obtaining results of the real behavior of the system. The experimental cells are designed with the aim of creating spaces subject to similar external conditions, where comparative experimentation is possible. This is achieved by designing two spaces of dimensions 3.30 m X 3.30 m X 3.30 m, dimensions as similar as possible to a living space, adapting to limited space availability. They have a total insulation of 51 cm thickness in all its faces and a transmittance of 0,072 W /m2 K.

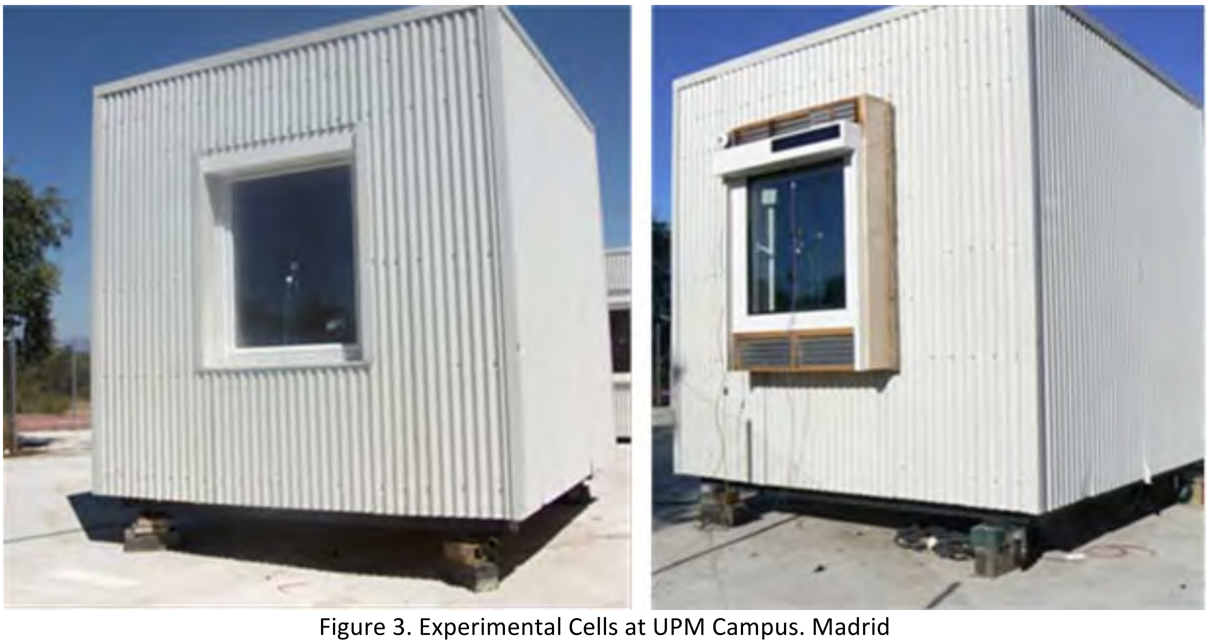


Figure 3. Experimental Cells at UPM Campus. Madrid

Samples

Table 1. Characteristics of Prototype window.

PROTOTYPE:CELL 1				
Frame	**Glazing**	**Wide (mm)**	**Height (mm)**	**Area (m²)**
Glasswin	Planitherm Ultra 4 mm / 16 /6 mm	1250	1500	1,875
Chamber	Air 225mm			
Eurofutur	Stadip6+6Planistar/16/Stadip 4+4			
VALORES GLOBALES DE LA VENTANA				
U	1,096 W/(m^2.K)			
Shading coefficient SC	0,345			
Visible Transmittance VT	0,465			

Table 2. Characteristics of reference window.

REFERENCE: CELL 2				
Frame	**Glazing**	**Wide (mm)**	**Height (mm)**	**Area (m²)**
Eurofutur	Planitherm Ultra 4 /12 / 4	1250	1500	1,875
VALORES GLOBALES DE LA VENTANA				
U	2,57 W/(m^2.K)			
Shading coefficient SC	0,513			
Transmitancia visible VT	0,692			

Monitoring

In cell 1 in the interior sensors of temperature, relative humidity and CO_2 are placed. For the analysis of the air renovation, five anemometers are placed, one in the extractor and another four in each one of the four grids. 24 thermocouples are placed in different elements: in the center of each surface of the module, one on the outside and one on the inside, one close to each anemometer, in order to analyze the operation of the thermal buffer created by the chamber. In the center of each glazing, inside and outside thermocouples are placed. To determine the efficiency of the heat exchangers, three thermocouples are placed in each one, one close to the outer face, another in the center and the third one in the interior. Finally, a pyrometer and a temperature sensor are placed on the outside. These elements are used for the double purpose of recording data and activating the active elements of the system: grids and blind.

In the same way as in Cell 2, temperature, relative humidity and CO_2 sensors are located in the interior. For the analysis of the air renovation, two anemometers are placed, one in the extractor and another next to the aerator grille located in the standard window, 12 thermocouples are placed: 2 thermocouples are placed in the center of each surface of the module, one on the outside and one on the inside, in this case no thermocouple is placed next to the anemometer as the air enters directly from the outside. In the center of the glazing element, one thermocouple is placed inside and one outside.

In addition, data from a weather station is taken.

The conditions established in both experimental cells are: indoor temperature is programmed to be maintained at 22 - 23 ° C; both heat pumps are on 24 hours, one air renovation is carried out per hour.

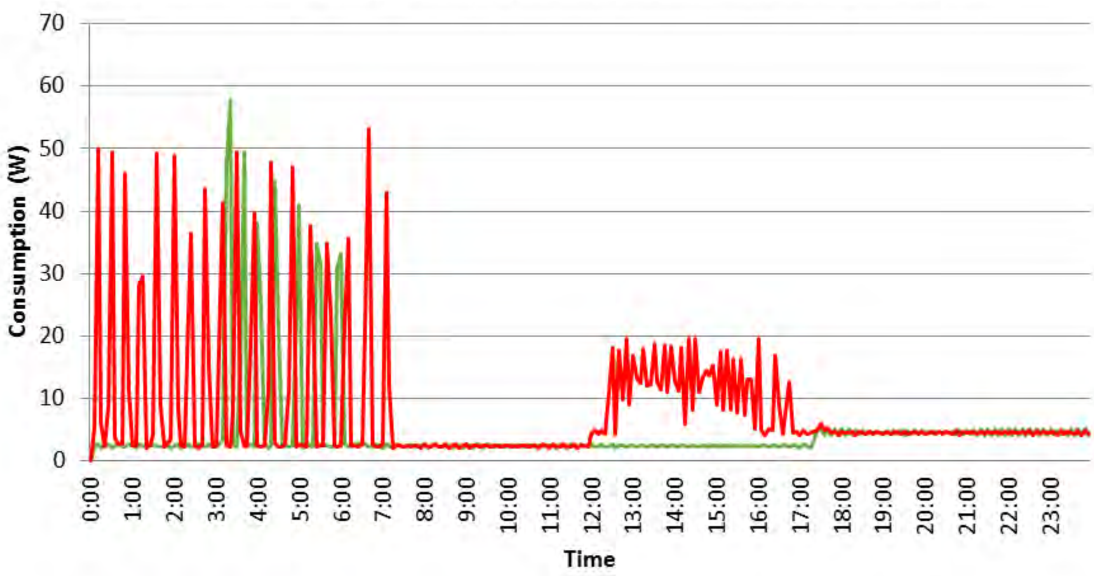
The drive of the systems is established according to the following set points: Text> 22ºC and Solar radiation> 800 W / m2

Results

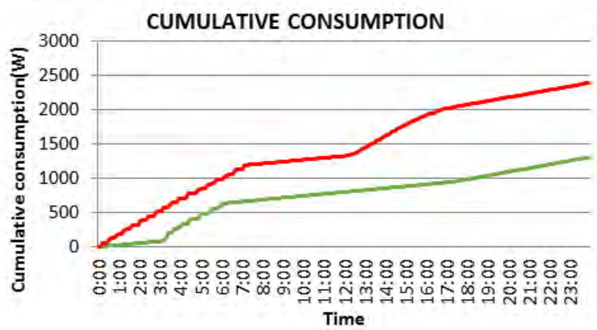
For nine months the HVAC consumption is obtained, the accumulative consumption is calculated and contrasted with interior and exterior temperatures.

Table 4: Daily Consumption results.

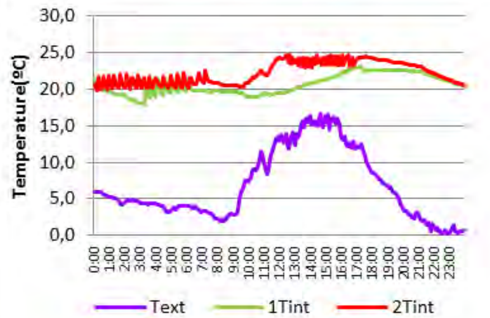
Jan. 28th HVAC Consumption. On green prototype window results, on red reference window data.



January 28th Cumulative consumption



January 28th temperatures



In a cold and sunny day (Example: January 28th) a reduction of up to 48% of consumption is obtained.

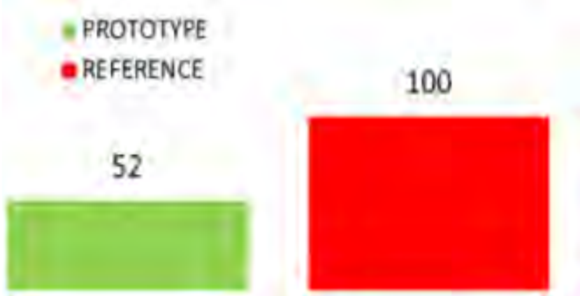


Figure 4. Reduction of consumption per day. (Example: Jan. 28th)

Bellow consumption reduction for each month is obtained.

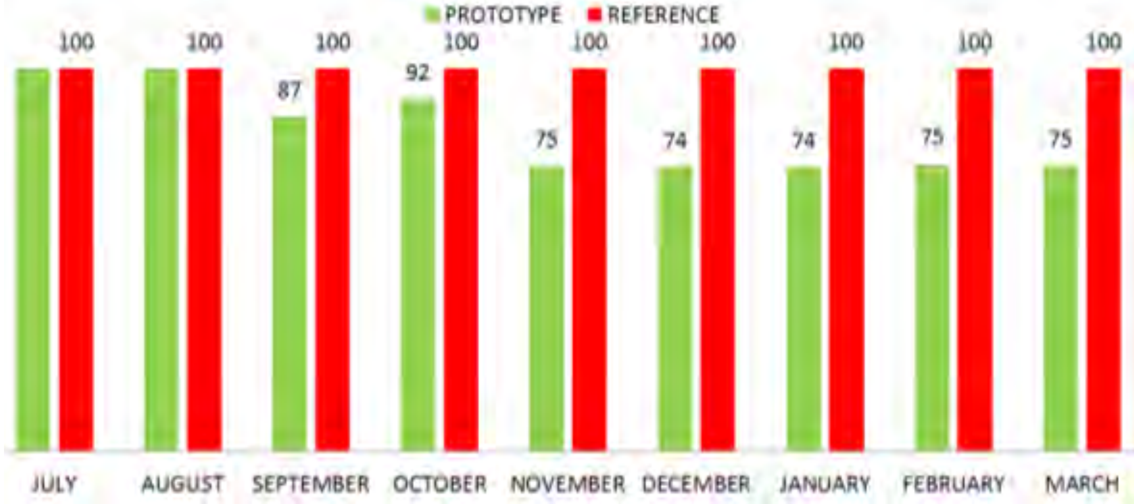


Figure 5. Monthly Consumption Results.

Results regarding the glazing system performance:

The analysis of data of different selected days is performed in order to confirm the system is functioning according to the design strategies:

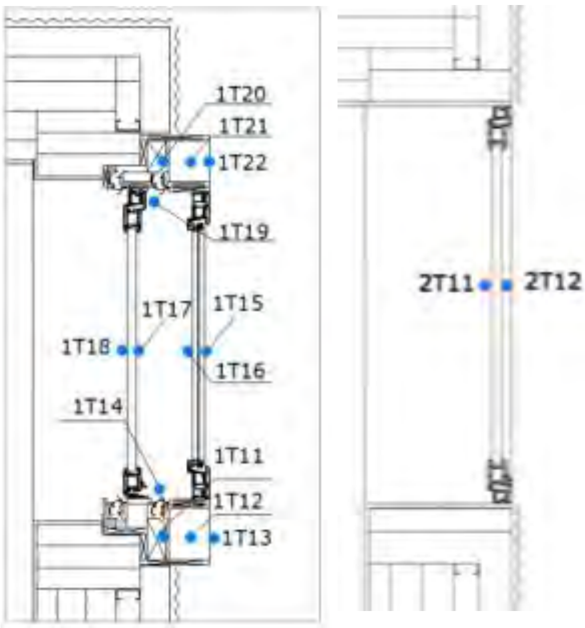


Figure 6. Thermocouples position in Prototype and reference window.

Summer position

In the air chamber a difference of 10ºC between the inner faces of the glazing is reached (1T15-1T17), which confirms the effect of the thermal buffer. Regarding the comparison between the prototype and the reference window a difference of 10ºC between sensors 1T17 and 2T12 is also confirmed.

Regarding the Heat Exchanger, the upper exchanger registers temperatures 15ºC higher than the lower one (Figure 7) and the upper and lower thermocouples of the chamber register ΔT=4ºC, the anemometers register the increase of speed in the hours of higher temperatures. Everything indicates the chimney effect caused by the design is working.

Winter position, low solar radiation:

In the air chamber there are between 4 and 9 ºC of difference between the sensors of the chamber, observing the thermal buffer effect. A similar ΔT is also confirmed between the 1T17 sensor of prototype and 2T12 sensor of reference window.

Regarding the Heat exchanger even with low solar radiation, the upper heat exchanger registers temperatures up to 8 ºC higher than the lower heat exchanger (Figure 7), and the thermocouples 1T14 and 1T19 in the chamber record a temperature increase of between 2 and 5 ºC.

Winter position, high solar radiation:

The chamber acts as a solar capturing element. The temperature in the 1T17 thermocouple is between 7 and 11 ºC higher than that of the 1T15 thermocouple.

1T17 sensor in the prototype presents a temperature 10ºC higher than 2T12 sensor of reference window.

Both Heat Exchangers register temperatures above the outside temperature, the upper one registers temperatures up to 13ºC above the lower and the thermocouples 1T14 and 1T19 in the chamber register a temperature increase of up to 12ºC. (Figure 7)

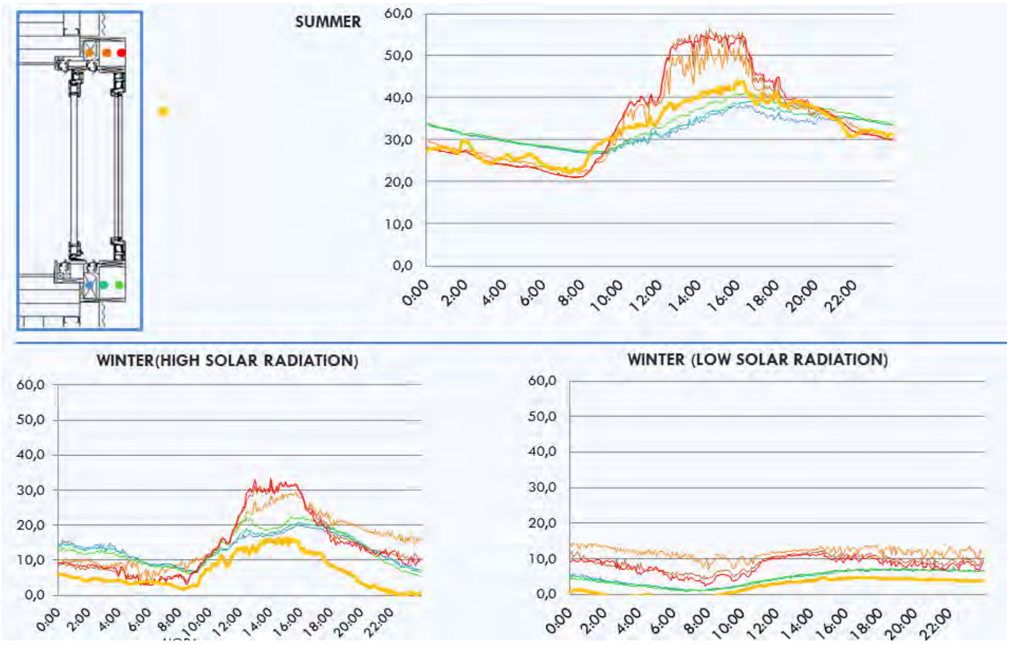


Figure 7. Thermocouples data in Heat Exchanger.

Conclusions

It is observed that the greatest consumption occurs in the summer months due to refrigeration, followed by the heating consumption during the winter months. In December, January, February and March, the reduction in HVAC consumption is 25% in Prototype cell in relation to Reference Cell, due to the use of solar radiation. In months September, October and March there is also a reduction of between 5 and 15%. In summer the consumption of both cells is equal.

The objective of using solar radiation is reached and is reflected in the reduction of consumption in heating up to 25% in heating in the cold months without penalizing the consumption in refrigeration.
The scheme of operation of the prototype, in view of the results, can be considered optimal for the climate of Madrid.
In terms of the performance of the active glazing panel, by analyzing the monitoring data of the selected days, the operation of the active glazing panel is confirmed according to the starting strategies defined for its design. The effect of the thermal buffer is confirmed by checking the surface temperatures of the glazing.

Table 5. Surface temperatures of the glazing

	Summer	Winter (high radiation)	Winter (low radiation)	Autumn (high radiation)	Autumn (low radiation)
ΔTmax	-10 ºC	+20 ºC	-9 ºC	+10 ºC	-4 ºC

The Heat Exchanger registers corresponding temperatures for optimum operation at different times of the year.

Table 6. Heat Exchanger temperatures.

	Upper Heat Exchanger			Lower Heat Exchanger		
	Tmax	ΔT day	ΔTmax	Tmax	ΔT day	ΔTmax
August 10th	55 ºC	34 ºC	10 ºC	41 ºC	13 ºC	4 ºC
October 11th	40 ºC	23 ºC	4 ºC	33 ºC	11 ºC	2 ºC
October 18th	24 ºC	11 ºC	4 ºC	22 ºC	5 ºC	1,5 ºC
January 7th	14,5 ºC	7 ºC	6 ºC	7,5 ºC	6 ºC	1 ºC
January 28th	33,6 ºC	25 ºC	6 ºC	22 ºC	15 ºC	3 ºC

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Design to Thrive

The Sustainability Assessment of Window Design in Patient Rooms in Hospitals

Nazanin Eisazadeh[1] and Karen Allacker[1]

[1] Architectural Engineering Unit, Department of Architecture, Faculty of Engineering Science, KU Leuven, Belgium, nazanin.eisazadeh@kuleuven.be

Abstract: Facades are a crucial interface between the external conditions and the required conditions inside a building. Using glazing in the building envelope provides daylight, views and ventilation. Windows can hence contribute significantly to indoor environmental quality and impact patients' recovery and length of stay in hospitals. Even though windows have many advantages the energy exchange through glazing has an important impact on heating and cooling loads in buildings. Window performance has improved over the years by using double and triple glazing, low-e coatings and argon and krypton gas fill. More recently, novel glazing technologies have emerged that promise further improvement of window performance; examples are smart windows, advanced coatings etc. This paper investigates the role of the glazing type and window design on energy efficiency and daylighting in a sample patient room. A preliminary study has moreover been performed on the environmental impact of these windows from a life cycle perspective. Simulation of the energy consumption and daylighting were conducted using the DesignBuilder software. Designing and evaluating window systems becomes complicated when energy efficiency, daylighting, comfort, environmental impact and cost are considered simultaneously. Hence, this paper is an initial step towards such a holistic approach.

Keywords: Sustainability, Energy efficiency, Daylighting, Environmental impact

Introduction

In the European Union 40% of total energy consumption is due to the building sector (Stazi et al, 2012). Hospitals are considered one of the most energy demanding building types and patient rooms occupy the largest space of hospital buildings (Sherif et al, 2014). Recently, more attention is being paid to comfort and potential non-visual effects of daylighting on well-being, productivity, sleep quality, stress reduction, etc. (Choi et al, 2012) (Vanhoutteghem et al, 2015). As windows play a major role in both energy loads and quality of the indoor environment, analysing the role of window design on building sustainability is seen essential.

A major issue when assessing the sustainability of windows, is their energy performance. The energy performance of windows is influenced by several factors: U-value (thermal transmittance), SHGC (solar heat gain coefficient), climatic conditions, orientation and building parameters (Vanhoutteghem et al, 2015). The U-value indicates the rate of heat transfer through a window (Jaber and Ajib, 2011) and SHGC is the fraction of solar radiation directly transmitted through a window and inward flowing solar energy absorbed by the glazing (Carlos and Corvacho, 2015). If the building is highly insulated the main external heat gains and losses occur through the window, making the task of designing the window become more challenging.

When assessing the sustainability of windows it is not sufficient to evaluate the influence of windows on the energy performance of the building and the need for artificial lighting. The full life cycle of the window should be considered, including the environmental impact related to material production, maintenance and end-of-life treatment. LCA (life cycle assessment) is an internationally accepted method to quantify these life cycle environmental impacts.

In order to avoid high energy loads, selecting the appropriate size, proportion, shape, location and type of window along with the orientation and shading are a fundamental part of early design stage decisions, and are difficult to change later on. This can be achieved by obtaining an integrated performance analysis where the link between various window design parameters and their combined effect on energy consumption, comfort, environmental impact and cost are considered. This paper presents an integrated approach to find a balance between increasing energy efficiency while maintaining a comfortable and healthy indoor environment with the least environmental impact. The methodology combines energy simulation, LCA and daylighting analysis.

State of the art

While there are many studies on window design with regard to energy consumption, comfort and lighting in office buildings (Ochoa et al, 2012) (Susorova et al, 2013) (Tzempelikos and Athienitis, 2007) these topics have been less explored in hospitals (Alzoubi et al, 2010) (Sherif et al, 2014). Literature review showed that previous research on windows performance mainly focus on energy, daylighting, thermal comfort (Manz and Menti, 2012) (Ochoa et al, 2012) (Sherif et al, 2014) (Skarning et al, 2016) (Stegou-Sagia et al, 2007) (Tzempelikos and Athienitis, 2007) (Vanhoutteghem et al, 2015) and less attention is paid to the environmental aspects (Citherlet et al, 2000) (Papaefthimiou et al, 2009).

Designing and evaluating window systems becomes complicated when energy efficiency, daylighting, comfort, environmental impact and cost are considered simultaneously and all window design parameters (glazing properties, frame, size, shading…) are taken into account. Hence, this paper is an initial step towards such a holistic approach.

Methodology

A simulation analysis was performed to investigate the effect of glazing type, orientation and shading on energy consumption, environmental performance and daylighting in a patient's room in a hospital. This section presents the parameters used and assumptions made for this analysis.

The simulation analysis was performed assuming a base case as reference and varying one parameter at a time in the model. This approach is chosen to compare the effects of one parameter in detail while all the other parameters are fixed. The sample patient room was used as the base case and glazing, orientation and shading as the variable element. For each variation, the operational energy, the life cycle environmental impact and the daylight availability were analysed.

Window system

The aim of the analysis of the window system was to analyse the overall performance of glazing systems in (1) existing buildings (basic scenario) compared to (2) a glazing system with improved characteristics in terms of light and UV transmitted and (3) a glazing system with improved characteristics in terms of solar control and heat resistance. The second type of glazing is selected for its potential positive impact on patient's health and the third type of glazing is selected based on its beneficial influence on heating demand and overheating issues.

The double glazing selected consists of two 4 mm glass panes and a 15 mm spacer with argon as gas fill. Additional optical and thermal properties of the selected double glazing are presented in Table 1.

I. Basic window: Base for comparison; the U-value and SHGC value are similar to double glazing used in existing buildings
II. Low Iron window: High light and UV transmission
III. Coated window: Solar control and high thermal insulation

Table 1. Properties of the double glazing

Glazing	Light Transmission	SHGC	U-value (W/m^2K)	Glazing Characteristic
I	0,82	0,79	2,50	Uncoated
II	0,84	0,84	2,50	Low Iron
III	0,72	0,53	1,10	Coated

The shading devices considered in the analysis are overhangs of 0,50 m for the South orientation and louvres and inside roller shades for the East and West orientations. The louvres have 7 blades with 0,20 m spacing and 0,20 m depth; the roller shade has a 0,40 solar transmittance and 0,45 reflectance with 0,1 conductivity (W/mK).

Model specifications

An actual patient room plan and construction detail from a hospital under construction in Belgium was used for the simulation. The room has one external wall with a single window; all other surfaces are assumed adiabatic (absence of thermal exchange). The external wall measures 4,0 m (width) x 6,0 m (depth) x 3,0 m (height). The window is 1,5 m x 2,4 m (height, width) with a 0,8 m sill height. U-Value of the external wall equals 0,218 W/m^2K and the wall is 0,42 m thick. Room heating and cooling set-point temperatures were assumed to be 22°C and 24°C respectively, relative humidity between 30 to 60% and mechanical ventilation was set to 2 (ac/h); these numbers are in accordance with standards provided for patient rooms (Environmental Design: CIBSE Guide A, 2006). Internal gains from people (104 W), lights (2,80 W/m^2) and equipment load (3,58 W/m^2) are modeled based on a 24 hours x 7 days occupancy schedule. The three windows have been simulated in this patient room: Room A (basic window), Room B (low iron window) and room C (coated window).

The simulations are made for the three models with windows facing North, South, East and West; with/without shading. No external obstructions were taken into account. EnergyPlus weather data for Brussels (latitude 50,90 and longitude 4,53) was used for the calculations. Simulation of the energy consumption and daylighting were conducted using the DesignBuilder software; DesignBuilder uses EnergyPlus as energy simulation engine and Radiance for daylighting. The environmental impacts were calculated at material level with Simapro (LCA software) and at building level with the KULeuven-MMG tool.

MMG is an expert calculation tool for the quantification of the environmental performance of building elements, specific for the Belgian context. In this tool, the generic LCI (life cycle inventory) data (Ecoinvent) are adapted to the Belgian context. The impact assessment method in the MMG methodology combines environmental impact categories from the CEN standard (EN15978), referred to as CEN indicators, and additional ones in line with the ILCD handbook, referred to as CEN+ indicators. The CEN indicators include global warming, ozone depletion, acidification, eutrophication, photochemical ozone creation, abiotic depletion resources-elements, abiotic depletion-fossil fuels and the CEN+ indicators cover human toxicity, particulate matter, ionising radiation: human health, ionising radiation: ecosystems, ecotoxicity, water scarcity, land occupation, land transformation. To allow for a decision-oriented selection, the characterised values for each individual environmental indicator can optionally be multiplied with a monetisation factor. This factor shows the extent of the potential damage to humans and/or the environment, expressing it in a financial amount for the purpose of avoiding potential damage or settling any damage sustained (Environmental profile of building elements, 2013).

Step 1: energy analysis

The aim of the first step was to calculate and compare the annual energy consumption expressed in kWh associated with heating and cooling for all 27 cases.

Step 2: environmental impact

The goal of this step was to determine the environmental impact associated with production, maintenance and disposal of the three glazing types and to calculate and compare the life cycle environmental impact of the rooms. Ecoinvent was used for the LCI data of the basic double glazing LCA. The coated and low Iron glazing were however not available in Ecoinvent. For these, EPD (environmental product declaration) data were used for the impact of the CEN-indicators related to the production phase, while the CEN+ indicators were approximated by the impact of the double glazing. For the modelling at the room level, the operational energy (heating, electricity) was estimated with DesignBuilder and imported in the MMG tool to calculate the related environmental impacts.

Step 3: daylighting analysis

In this step a simulation-based daylighting analysis for the rooms in an overcast sky condition was carried out. The target illuminance for this case is 125 lux and the reference plane is the patient bed level plane (0,90 m height). It should be noted that one third of the room is service area (across the window wall) and does not require daylighting.

Results and discussion

Results step 1: energy analysis

The annual energy consumption in all models was dominated by heating, than followed by cooling as shown in Figure 1 and 2. The annual energy consumption for Room A and Room B are similar and significantly higher than for Room C, in all orientations without shading devices. Figure 3 and 4 highlight the fact that basic and low Iron windows allow for more solar gains and higher heat loss compared to the coated window. The percentage of energy savings from coated glazing compared to the other two glazing types ranges from 19% to 23% in all orientations. Among all models, the North orientation has the highest heating energy as a result of low incident solar radiation (low solar gains). The cooling energy is 13% to 15% less in East oriented models compared to West oriented models under same conditions due to higher temperatures and solar radiation in the afternoon.

Shading has a major impact on cooling energy with savings from 25 to 40% in all orientations (no shading in north). The results show that the cooling energy of Room A and Room B with shading devices is close to or lower than Room C without shading devices.

Results step 2: environmental impact

In this step the life cycle environmental impact was calculated. The findings show that the coated window has a lower environmental impact compared to the other two window types. Room C has the lowest environmental impact due to the energy saving provided by coated glazing. From Figure 5 and 6 it is possible to deduce that low Iron window and Room B lead to the highest environmental impacts, although the differences are minor/negligible compared to the basic window and Room A.

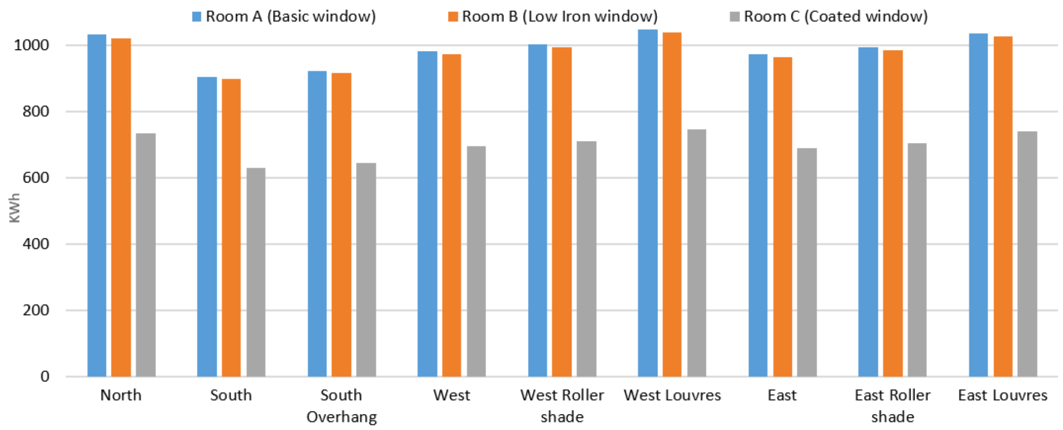

Figure 1. Annual heating energy

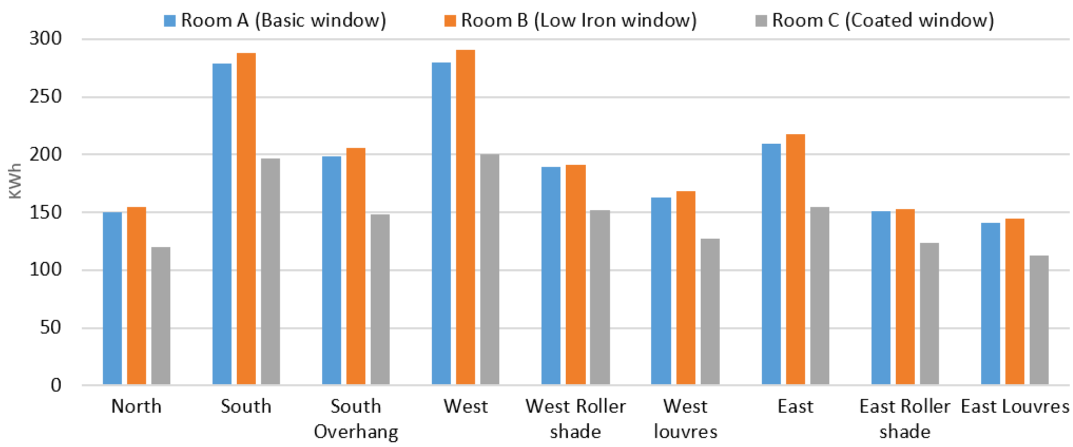

Figure 2. Annual cooling energy

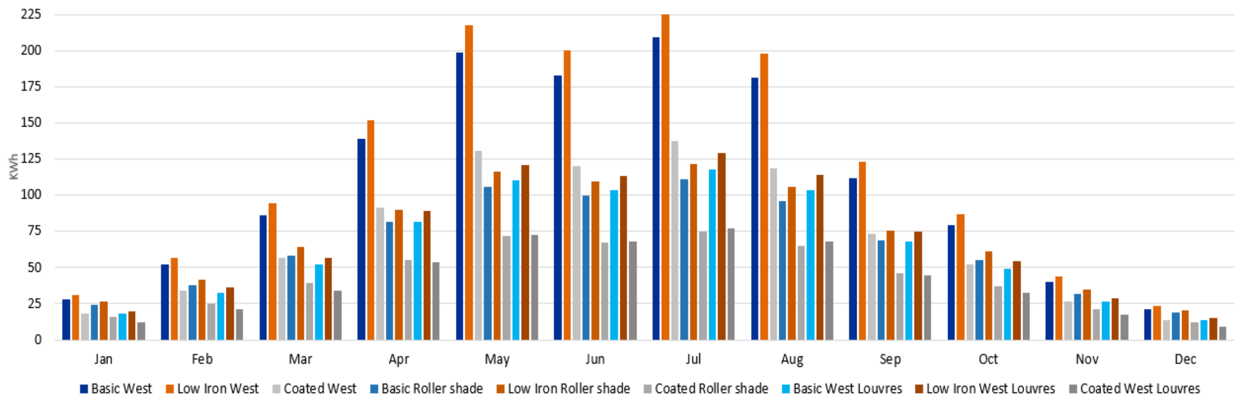

Figure 3. Solar gains windows in West with/without shading

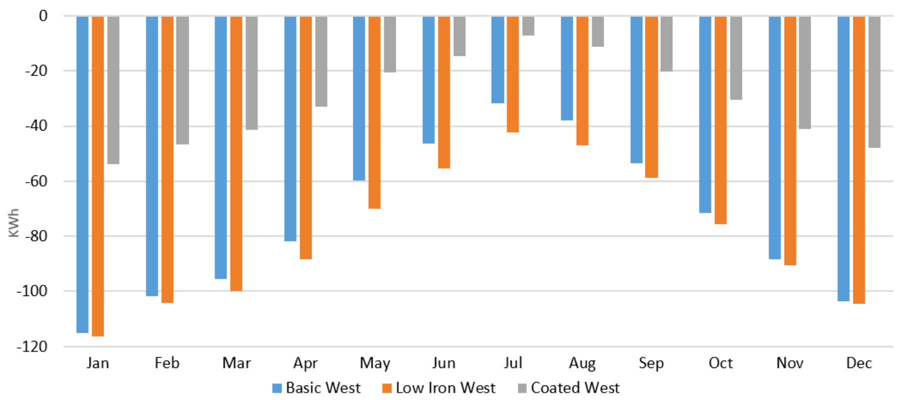

Figure 4. Heat Loss in West oriented windows

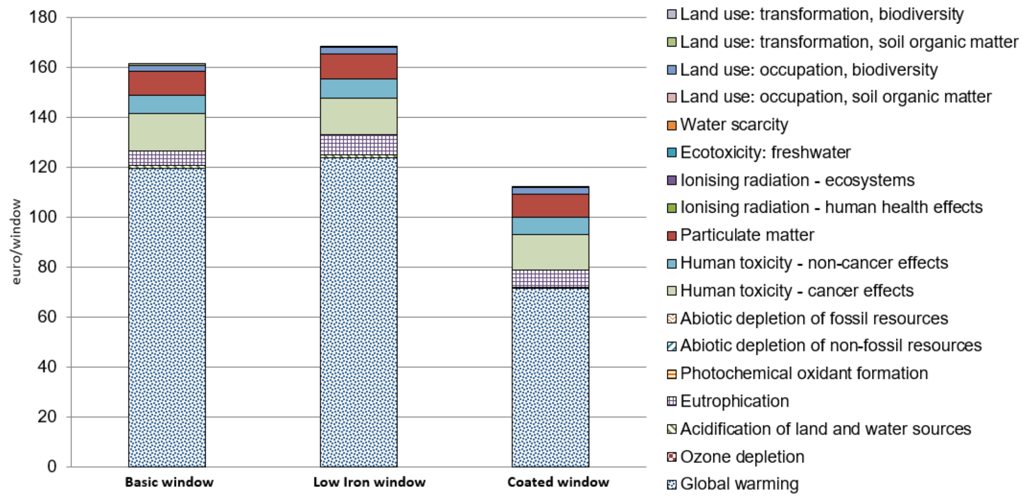

Figure 5. Windows life cycle environmental impact

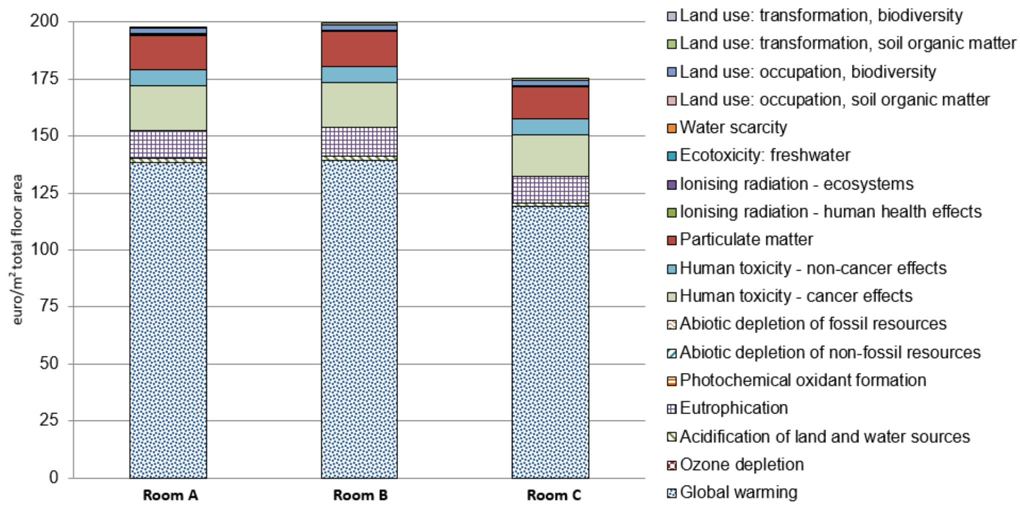

Figure 6. Patient rooms environmental impact

Results step 3: daylighting analysis

The spatial patterns of daylight presented in Figure 7 suggest that the daylight area extends across half of the room adjacent to the window in models without shading. The figure shows an overlit area (pink) near the windows (illuminance level is ten times more than target).

The average DF (daylight factor) is a measure of the amount of skylight in a room. An average DF of 5% or more will ensures a substantially daylit interior and an average below

2% generally makes a room look gloomy and artificial lighting is likely to be needed most of the day (Yarham, 1999). As shown in Table 2 the values are mostly above the recommended minimum DF of 2%. North oriented models achieve good DF averages and no discomfort glare by direct sunlight. The overhang in South oriented models reduce the solar gains and cooling energy in summer but keep the DF within an acceptable range. Fixed louvres in the East and West oriented patient rooms significantly reduced the DF. The findings suggest that using active shading devices in West and East orientations may be a better option for satisfying both energy saving and daylighting criteria at the same time. As expected Room B with low Iron window has the highest DF averages on all sides due to high light transmittance but the difference compared to the other models is rather small.

Table 2. Average DF of models

Average Daylight Factor (%)	Without Shading				With Shading		
Orientation	North	South	East	West	South	East	West
Room A (Basic window)	3,77	3,83	3,82	3,79	2,90	1,47	1,51
Room B (Low Iron window)	3,89	3,94	3,96	3,86	2,98	1,53	1,57
Room C (Coated window)	3,22	3,30	3,31	3,26	2,50	1,28	1,31

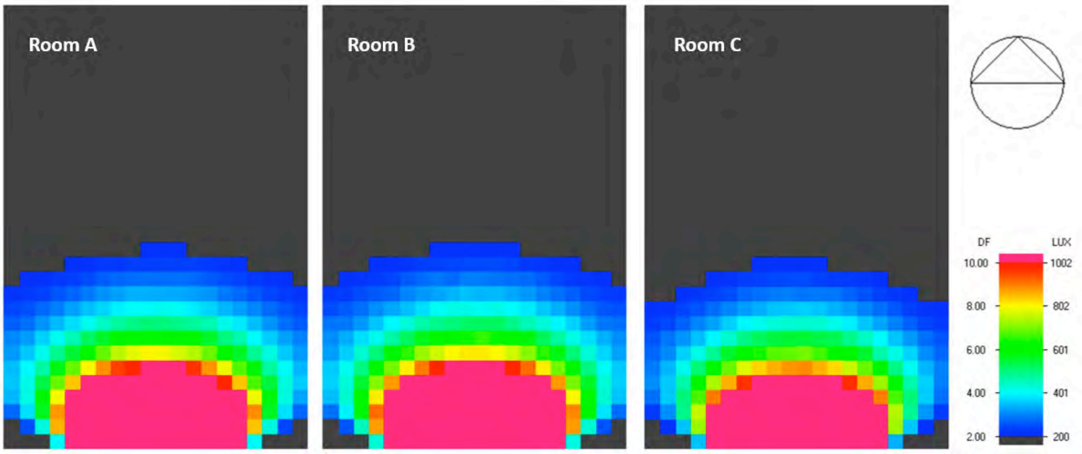

Figure 7. Illuminance map of south oriented rooms without shading

Final results

In Belgium the main factor for window selection to date is influenced by the heating loads but the results demonstrate that the effect of the window on the cooling loads should be considered as well. From the three windows assessed, the models with the coated window have the best overall performance; showing the importance of glazing characteristics in window design. The simulations moreover highlighted that a solar control coating allows for efficient daylighting without the risk of overheating.

The models with the low Iron window have the lowest overall performance; the high solar gains in summer increase cooling energy approximately by 30% compared to models with the coated window. Additionally, the illuminance maps and DF averages show that the effect of the low Iron characteristic does not particularly contribute to optimal daylighting and does not compensate for the high energy consumptions and environmental impacts.

The results moreover show that shading devices have a major impact on energy saving and daylighting and in order to achieve an overall good performance, using active shading devices in West and East orientations may be a better solution compared to fixed devices.

Conclusion

This preliminary simulation analysis was useful to evaluate the combined effect of various glazing and window design parameters on energy consumption, daylighting and the environment. This paper demonstrated that window systems have a significant impact on energy loads, environmental impact and illuminance and selecting the optimal system is a very important issue to be addressed in the early design stage. The results indicate that focusing on individual aspects is not sufficient to get a correct insight in the window system's performance and an integrated approach is required to simultaneously consider all aspects.

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Design to Thrive

Façade design and energy demand: fenestration indexes from an urban approach

Elena Garcia-Nevado[1], Benoit Beckers[2] Helena Coch Roura[1] and Isabel Crespo[1]

[1] Architecture & Energy, School of Architecture of Barcelona, Universitat Politècnica de Catalunya (UPC). Av Diagonal 649, 08028 Barcelona, Spain. elena.garcia.nevado@upc.edu
[2] Department of Building and Public Works (ISA BTP). Université de Pau et des Pays de l'Adour (UPPA). Allée Parc Montaury, 64600 Anglet, France. benoit.beckers@univ-pau.fr

Abstract: Façade design has significant effects on inner conditions of spaces and also on the energy needs to achieve user's comfort. In this regard, the proportion of glazed surfaces to opaque ones plays a key role. Although the link between the fenestration ratio and energy demand for a space has been widely addressed in literature, a considerable number of these studies were based on isolated models, disregarding the effect of the urban surroundings. The aim of this paper is to provide insights on the impact of the window-to-wall ratio (WWR) on thermal energy demands taking into consideration a specific urban context. The *Eixample* district of Barcelona, with Mediterranean temperate climate, has been selected as the case study. Heating and cooling energy needs have been evaluated for a single residential space by means of computer simulations in Design Builder for different positions within the tissue. Results show that, from a thermal point of view, the design of façade openings within an urban context should vary depending on the orientation and the degree of obstruction, as a reflection of the differences in energy balance within the building envelope.

Keywords: Window-to-wall ratio, Mediterranean climate, Energy demand

Introduction

Building envelope, as the filter between outside and inside spaces, poses an environmental challenge for architects. Among all surfaces composing this enclosure, façades have been found to be decisive for environmental conditions inside buildings and, consequently, for energy requirements to maintain user's comfort levels.

Regarding the façade design, one of the first early-stage decisions made by designers is the proportion between glazed surfaces and opaque ones. For a particular space, this geometrical relationship may be expressed through two parameters: window-to-wall ratio (WWR) and window-to-floor ratio (WFR). Both indexes have been recurrently employed in literature to describe the link between fenestration design and inner environmental conditions regarding lighting (Bodart & De Herde, 2002; Ghisi & Tinker, 2005) and heat (Persson et al., 2006; Inanici & Demirbilek, 2000) either as individual aspects or from global perspective (Ochoa et al., 2012; Skarking et al., 2016).

One common approach for studies on the correlation between WWR and energy needs is to conduct their analyses based on a spatial model – usually a shoebox – conceived as an isolated entity. This definition of the study problem constitutes a logical starting point on the matter and allows us to provide valuable and straightforward insights for a simple, yet feasible, scenario. However, the final energy impact of windows on indoor environment not only depends on the element features itself but also on geometrical and material characteristics of the urban surroundings.

Investigations taking into consideration the effect of urban context are, though, much more limited. Some studies have been carried out defining a simplified urban context by using the endless canyon scheme. For example, Hegazy et al (2013) studied the combined effect of window size and shading device on daylight autonomy and energy consumption in Cairo. In this work, the complex balance between reducing air conditioning demands and lighting needs in the case of cooling-dominant climates was highlighted.

Despite the usefulness of the urban canyon approach, this model overlooks the 3D complexity of urban environments regarding local energy changes due to street intersections (Garcia-Nevado et al., 2016) and other non-canyon-shaped configurations (e.g. squares). In this sense, analysis based on urban tissue samples could contribute to a better understanding of the implications of urban façade design under more realistic conditions.

Based on a complex 3D environment, Fernández et al (2016) demonstrated that, results of window layout optimisation may differ depending on whether urban surroundings are taken into account or not. In the same vein, Vermeulen et al (2013) carried out an optimization analysis of the form and the façade layout for a block located in neighborhood of Paris. Results of this work suggested that, for heating-dominant climates, the optimum size of openings mainly depends on orientation and urban obstruction.

As shown, the role of façade design from an urban perspective is still in need of further research. This paper aims to provide additional insights on the impact of glazing ratio on thermal energy demands taking into consideration a specific urban context. This work focuses on a temperate climate, where heating and cooling needs have to be considered during the design process with regard to urban solar obstructions.

Method

In order to discuss the impact of WWR on thermal performance of spaces located in a specific built environment, a four-step method has been developed. First, the basic simulation model to be tested within a certain urban context is to be designed. The basic model is conceived as a single-space box with just one exterior façade where a variable-sized window will be located.

Second, the urban context where to study effects of WWR changes is to be modelled. The urban model consists of a central block - where the basic model will be integrated - surrounded by the minimum number of additional blocks which reproduce a representative sample of the chosen tissue.

Third, a parametric study of the thermal behaviour of the base model is performed in terms of WWR for the previously-defined urban model. To this end, heating, cooling and total air conditioning demands are selected as assessment parameters. These parameters will be calculated by means of computer-based energy simulations on an annual basis.

Finally, an optimisation analysis of WWR is carried out for the selected urban context. The optimisation problem consists in minimising a single objective function, in our case, global air-conditioning demands. Two optimisation scenarios are analysed on the basis of the constraints imposed to the glazing ratio solutions. On one hand, the optimisation problem is solved with no constraints about either the minimum or maximum WWR. On the other, the optimisation assessment is performed fixing a minimum WWR and applying a tolerance range on the minimum demand of a 10%.

Case study

Base model description

The base model of the present case study consists of a shoebox (width·depth·height = 6m·6m·3m) representing a sample of a single residential unit. The model is completely enclosed by adiabatic surfaces except for one, the exterior façade, where a single window is placed. The WWR of the space is parametrically defined between 0% and 100%, in 10% steps. No shading devices have been taken into consideration. Thermal features of the base model are detailed in Table 1.

Table 1. Base model features.

Façade materials	Exterior wall	Brick wall (12cm) + air cavity (5cm) + Brick wall (6cm) [U=1,92 W/m^2]
	Window	Single glass (6mm) + aluminium frame without thermal bridge break [U=5,7 W/m^2; g = 0,8]
Partitions	Horizontal	Concrete joists & ceramic blocks (20cm) + floor slab (5cm)
	Vertical	Brick wall (12cm)

Urban context definition

The *Eixample* district of Barcelona has been selected as case study. The original urban plan was conceived by Idelfons Cerdà (Cerdà 1867) in response to the unhealthy conditions of the overcrowded industrial city. It consists of an orthogonal grid of streets with 45º North orientation whose basic repetition unit was a slightly chamfered square (113x113m).

As a result of speculative processes, the *Eixample* resulted to be a much more densely built urban structure than the one initially planned. For this work, the profile of the block where the base model will be tested is defined according to regulations into force between 1932 and 1976 (CCCB 2009). During this period, highest densities and land occupations were reached posing a critical scenario in terms of solar access.

The present case study comprises a sample of 9 blocks (3x3). The base model is evaluated for several representative locations within the centre block of the tissue in order to analyse thermal behaviour differences in height. These positions correspond to the middle point of each block facet at two different levels (L1, L5) (Figure 1).

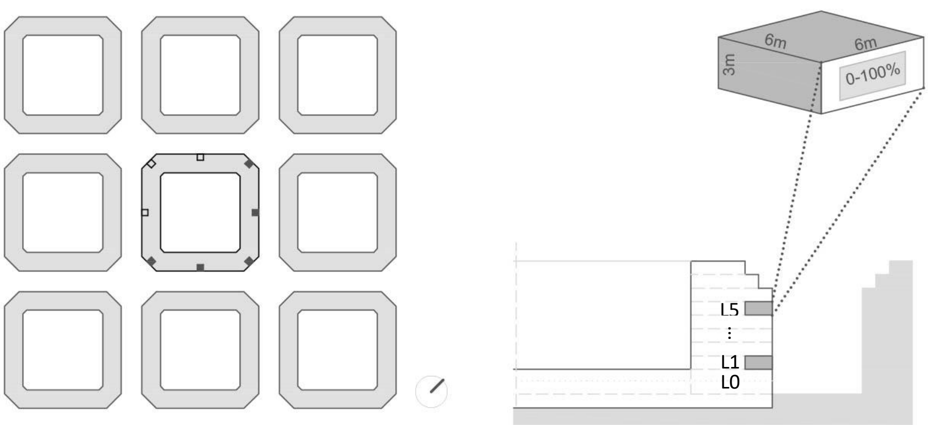

Figure 1. Plan (left) and section (right) of the *Eixample* tissue and selected locations for the test model.

Within the *Eixample* block, two kinds of façades can be identified: chamfer and long façade (Figure 2). The former, belonging to a square-shaped space, presents a lower degree of sky obstruction than the latter, pertaining to a canyon-shaped space. In sight of solar obstruction diagrams, it can be stated that more significant differences in height are found in longer façades (SW/SE, NW/NE) than in chamfer ones (E/W, N, S) regarding solar radiation availability.

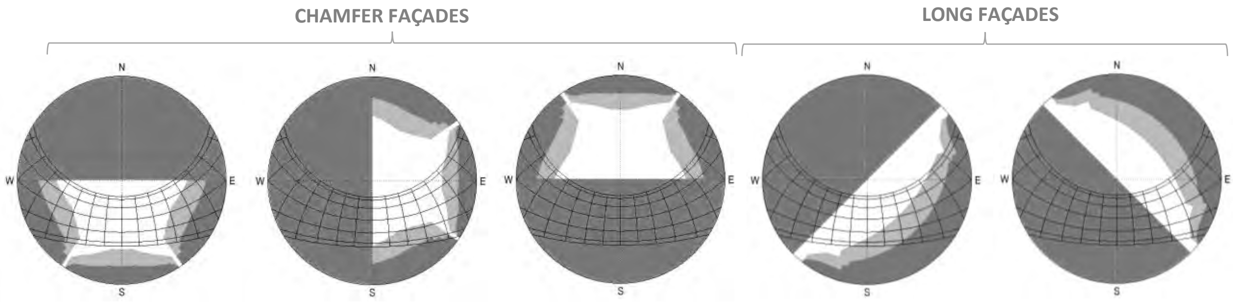

Figure 2. Solar obstructions in stereographic projection for L1 (dark grey) and L5 (light grey) for S, E, N, SE and NE façades, calculated in Heliodon (Beckers & Masset 2006).

Simulation settings

Energy simulations have been conducted using the software Design Builder v.5. This tool computes heating and cooling loads of spaces through dynamic thermal simulations based on climate data. Energy calculations in this software take into account shortwave radiation interactions with the urban surroundings (obstruction of diffuse and direct radiation + source of reflected radiation). As for longwave exchanges, the urban environment is considered to be a sky view obstacle, which is at the same temperature as the air. An overview of the simulation settings used for the present case study is included in Table 2.

Table 2. Simulation settings.

User's profile	Residential use Occupation rate 0,04 p/m^2 Schedule 100% 23-7h / 25% 7-15h / 50% 15-23h
Location	Barcelona 41°N - IWEC Weather file
Set-point Temperature	Heating 21 °C Cooling 26 °C
Free cooling	21 – 24h from June to September
Infiltrations	0,5 ren·h^{-1}
Reflectivity	R_{GROUND} = 0.4 $R_{BUILDINGS}$ = 0.4

Results and discussion

Cooling, heating and global demands

Results of air-conditioning demands depending on WWR are shown in Figure 3 for rooms belonging to an isolated block and also for an urban one. Differences in energy requirements between E, SE, NE and W, SW, NW orientations respectively are barely noticeable on an annual basis; therefore, only the former have been depicted.

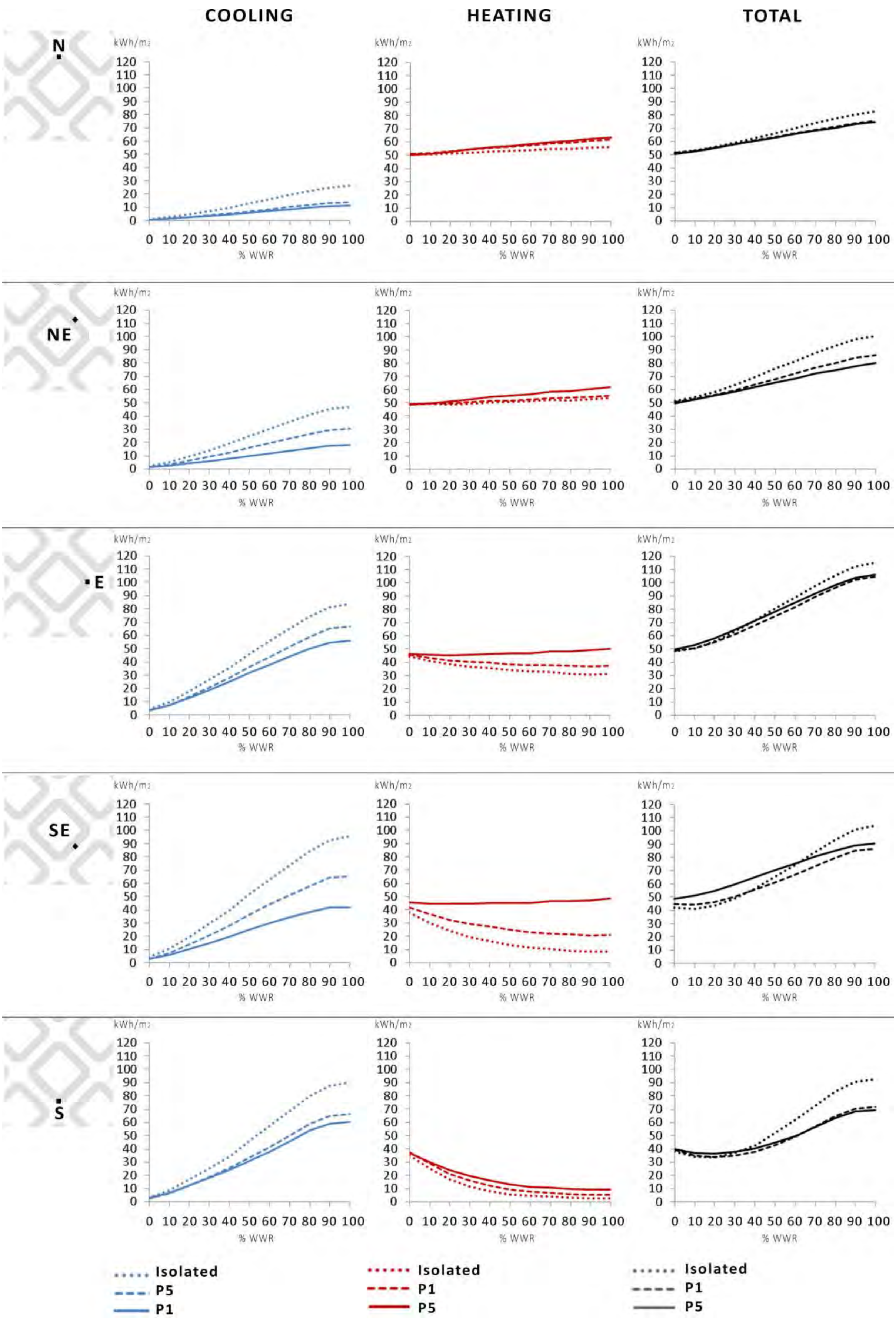

Figure 3. Air conditioning demands for an isolated and an urban block at levels P1 and P5.

Figure 3 shows that the increase in the opening size results in an almost linear rise in cooling requirements for all the analysed cases. Since cooling needs are mainly driven by radiation loads, the significance of this increase demand will depend not only on orientation but also on the degree of obstruction. Consequently, for the same orientation, the higher the floor level is, the more noticeable the increases in cooling demands are computed as openings enlarge. Changes in cooling demand due to higher WWR may be significant in both relative and absolute terms, increasing energy needs between 11 to 64 kWh/m^{2}year (in N-L1 and E/W-L5 cases, respectively).

As for heating demand, the enlarging of the glazed surface has uneven effects on energy requirements depending on the orientation and the degree of obstruction. On one hand, a decrease in heating needs is observed for south facing spaces and the less obstructed ones facing SE/SW and E/W orientations. This reduction in energy demand is explained by the fact that, for these locations, solar gains exceed conduction losses. Due to this effect, heating demand is reduced between 8 and 32 kWh/m^{2}year (in E-L5 and S-L5 cases respectively). On the other hand, the growth of the window size is associated to a slight increase in heating requirements for the rest of orientations regardless the height.

Regarding total air-conditioning demands, the parametric increase from 0 to 100% of WWR is linked in general terms to a rise in energy needs (ranging from a 1,5 to a 2,1 factor for N-L1 and E/W-L2 cases respectively). However, it is worthy to differentiate two particular situations in this regard. On one hand, for all N, NE, NW, E and W cases, the bigger the window is, the higher total demand is computed, reaching the minimum total demand for a 0% WWR. On the other, for S, SE and SW orientations the minimum air conditioning demand is reached between the 30% and 10% WWR.

Optimization of WWR to minimise total air-conditioning demand

In this subsection, the WWR optimization based on the minimisation of the total air-conditioning demand (T_{min}) is discussed. In this regard, two different scenarios have been assessed and graphically represented (Figure 4 and 5).

First, the “optimum WWR” for each case is determined as the glazing ratio linked to the minimum total air conditioning demand (T_{min}), without any further constraints on the window size. Though in this scenario lightning requirements may not always be fulfilled, it constitutes a conceptual approach on the thermal impact of the window size worthwhile to analyse. Results for this optimisation case are depicted in the elevation of Figure 4. Under this approach, windows would be present only in south façades and in the higher floors of southeast/southwest ones. These results indicate that, for the study case, the presence of glazing surfaces only has a positive thermal impact for S, SE and SW orientations and under highly-unobstructed conditions.

Second, the “optimum WWR” is defined as the maximum window size that does not lead to a “significant increase” in demand compared with T_{min}, being WWR≥ 10% in any case. For the present study, a “significant increase” has been defined as an increment of 10% of T_{min}. Block elevations based on these criteria are depicted in Figure 5. Urban façade design resulting from this thermal optimisation is characterised by a non-uniform layout. Differences in WWR glazing ratios are detectable between orientations. Additionally, for the more obstructed façades (SE, SW, NE, NW), they are also present in height, reflection of the link between obstruction and the window net energy performance.

It is worth-mentioned that the maximum glazing ratio obtained for this scenario (30%) is similar to the WWR average found by the authors in their ongoing research about fenestration in the *Eixample*. A possible explanation for this parallelism could be the existence of a non-explicit knowledge on the part of designers about certain façade configurations which pose a good compromise between thermal and lighting performance for this climate and urban context.

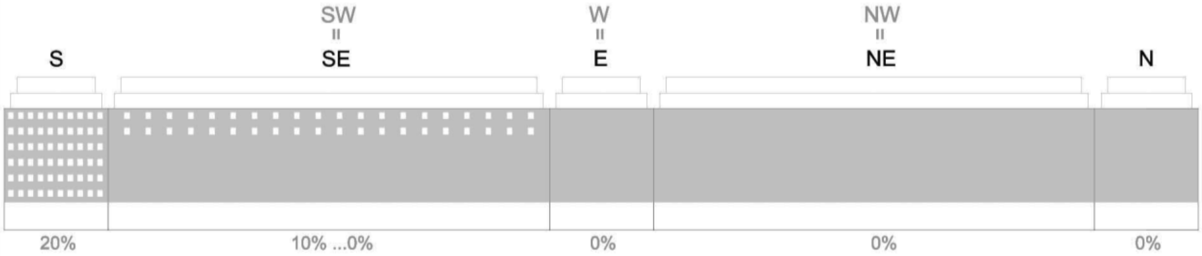

Figure 4. Elevation with WWR associated to the minimum air-conditioning demand.

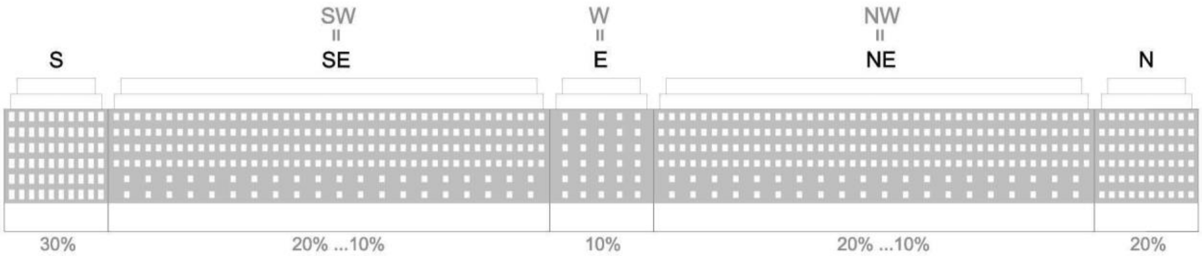

Figure 5. Elevation with WWR increasing by less than a 10% the minimum air-conditioning demand.

Conclusions

In this paper, the impact of WWR on air-conditioning demands has been discussed from an urban perspective. Results indicate that, for the climate of Barcelona, only the windows with a south component (S, SE, SW) on highly unobstructed contexts present a net positive effect from a thermal point of view. It has been shown that, for the urban tissue of the *Eixample*, WWR increases beyond a 30% always result in rises in total air-conditioning demands, regardless orientation and degree of obstruction.

In this work, a discussion on the possibilities of optimizing WWR to minimize air conditioning needs has been also carried out for the *Eixample* case. To illustrate conclusions on this point, a schematic view about a thermally optimised urban landscape of the *Eixample* has been included (Figure 6). The urban layout of the tissue is highlighted as one influencing factor regarding the obtained optimum glazing ratio. Consequently, façade design resulting from a thermal-based WWR optimisation differs among orientations. In addition to this, the optimum opening size from a thermal point of view grows in height (the higher the floor, the bigger the window) for the more obstructed façades.

The complexity of energy exchanges taking place through the building façade makes difficult for architects to understand the consequences of its design. Results of this work provide insights about thermal implications associated to changes in the WWR, an aspect which is present from an early stage of design. Findings on this paper may also contribute to a better understanding of the role of façade design regarding the thermal behavior of urban tissues.

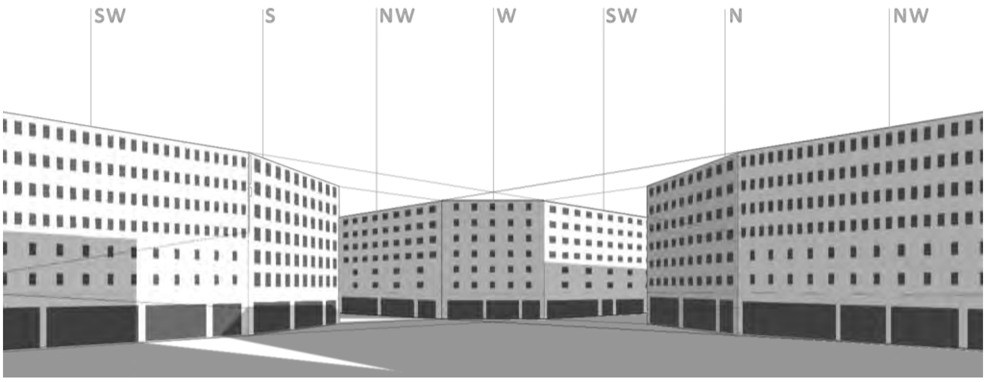

Figure 6. Urban landscape of *Eixample* with WWR which minimises air conditioning demands.

Acknowledgements

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Performance Evaluation of External Jaali Screens as Window Treatments in Warm and Humid Climate

Pavithra Radhai Kvn[1], Gayathri Sivakumar[2]

[1] Associate, Consultancy Division, Darashaw &Co.Pvt.Ltd, Chennai -600034
kvn.pavithra@gmail.com;
[2] Research Associate, Environment & Climate Change, Center for Development Finance
IFMR LEAD (Leveraging Evidence for Access and Development), Chennai - 600006
gayathricool2007@gmail.com

Abstract: *Jaalis* are perforated screens which were used as window treatments, predominantly found in Indian, Indo-Islamic and Islamic architecture. Historically, they have been extensively adopted in regions characterized by high solar radiation, to provide ample shade and privacy. In recent years, these screens are introduced for their aesthetical character. In a building envelope, glazing accounts for the major heat transfer into the built space, thereby increasing the cooling load. Appropriate shading of the glazed façade area, through *Jaali* screens serves as an effective strategy by reducing the high intensity radiation, thereby can cut down the energy loads considerably. The study aims at evaluating the performance of external *Jaali* screens as window treatments, through the design of a school in 'Warm & Humid climate' of Tiruchirappalli, Tamilnadu, India. Various permutations and combinations were used in devising optimum screen configurations for different orientations of the envelope, which ensures adequate shading when the intensity of radiation is above the shading line, such that the heat ingress into the building is obstructed. The shading criterion is adopted as per adaptive comfort model in ASHRAE 55. These are further tested using Ecotect and Radiance simulation tools for calculating shading and for their performance on Day lighting.

Keywords: External *Jaali* Screens, Solar radiation, Optimum Screen Geometry, Solar Shading, Day lighting.

Introduction

The windows account for the greatest amounts of heat entering the building and therefore shading them, offers the greatest protection" [Olgay, 1963, p72]. Solar shading affects the energy use in a building by reducing solar gains and modifying thermal losses through windows. Shading devices also influence day lighting levels in a room and the view to the exterior(Ayesha Batool, December, 2014). Shades are divided into four categories, such as shades, blinds, screens and switchable glazing(Dubois, 1997).

Shading of buildings with respect to both energy use and comfort is a complicated task. Fortunately, there are many studies that had been carried out in analysing the effect of shading devices on energy use and day lighting(Dubois, 1997). Solar heat gain reduction is of primary concern, to improve thermal comfort and subsequently reduce energy demand, thereby providing comfort to occupants in warm weather (Boake, 2014).

*Jaali*screens are perforated screens which are used as window treatments in traditional buildings(Kamal). Historically, these screens have been extensively adopted in regions characterised by high solar radiation, to provide ample shade and privacy. *Jaali*s are one of the architectural elements used from history which contributes to the user comfort. *Jaali* manages to cut down on direct sun and thereby the heat ingress. It also allows movement of air for cross breeze and ventilation.

Several studies have discussed the use of external *Jaali* screens for achieving indoor thermal comfort; whereas there is very sparse literature that addresses these screens quantitatively. A better understanding of the effect of screen geometry on energy saving can be used for developing new efficient designs that suit the harsh conditions (A. Sherif, 2012).

Rationale of the Study

The study focuses on breakdown of screen geometry with respect to the Altitude, Azimuth of the sun's position and the Global Horizontal Radiation (GHR).The criteria for shading needs are addressed for a classroom in a school building located atTiruchirapalli, India. Appropriate criteria for shading needs are devised byvarious geometries of the screen for shading the glazed fenestration for major orientations. The study limits only to the optimum screen geometry, where the material of the screen and type of glazing are kept constants. The study concerns only on the thermal and lighting performance of *Jaali*screens, while the ventilation strategy of the screen is not considered.

Climate Interpretation

Tiruchirappalli has a Warm & Humid climate with hot summers and dry winters. Temperature in this region generally ranges between 21°C to 38°C and is rarely below 19°C or above 40°C (Weather Spark).The bioclimatic chart is plotted for the average relative humidity with respect to average dry bulb temperature (NREL,EnergyPlus). From the chart, it is clear that natural ventilation is required throughout the year and the shading devices promote the air movement while obstructing the direct radiation from sun.

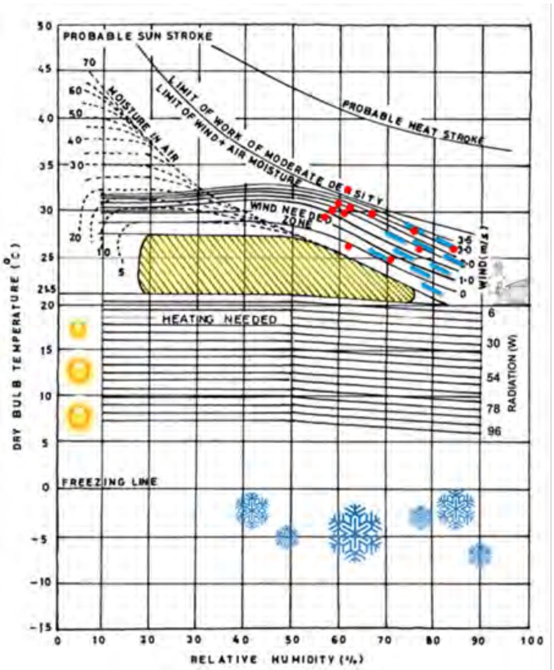
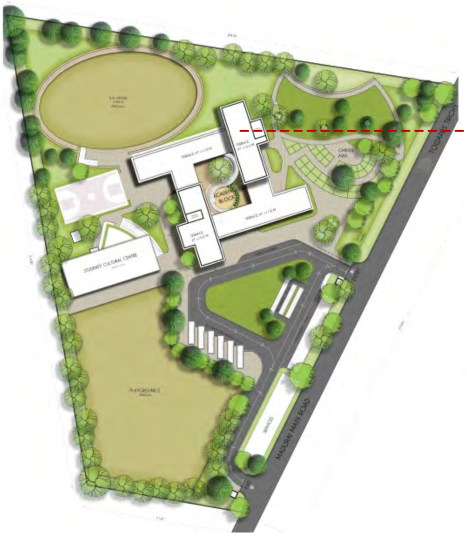


Figure 1.Bioclimatic chart of Tiruchirapalli

Design Considerations

The residential school building is located at a site, which is trapezoidal in shape, longer axis oriented along East – West, widespread to an area of 7.9 acres. An academic block of 1985 sq.m area is proposed along-17.5° North-South, which serves as the optimum orientation, due to the lesser incident radiation (Wh/m²) received on the surfaces (NREL,EnergyPlus).The form is evolved such that it addresses the major design consideration of shading, being mutually shaded during majority of the time of a year, with spaces organised along a central courtyard.



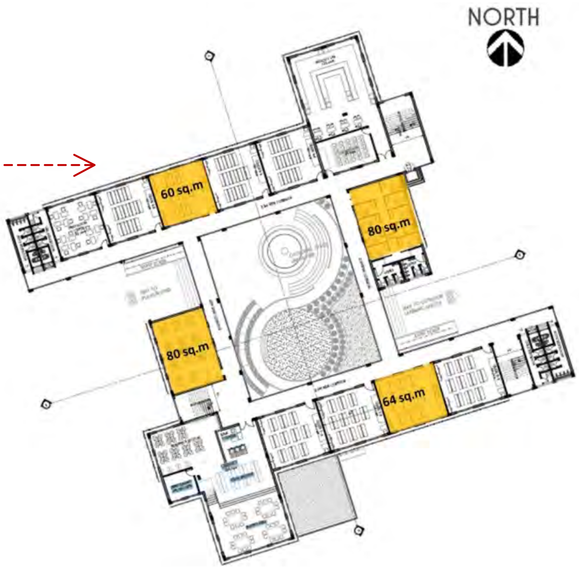


Figure 2.Site Plan showing the location of the Academic Block (Left)
Figure 3.Academic Block plan showing the classrooms (Right)

The academic block in Fig.3 shows four different classroom spaces in all four major orientations (North, South East & West), which is considered as sample for evaluation of shading and lighting for the *Jaali*screen configurations. The consideration taken for simulation using the Autodesk Ecotect simulation tool were, reflectivity of walls, ceiling and floor as 0.7, 0.8, 0.6 respectively, the work plane is kept constant at +0.6m from floor level, depth of the *Jaali*screen was kept constant at 5cm and the module sizes were devised for uniform size of (0.5 x 0.5) m and the material of *Jaali* screens was Glass fibre reinforced concrete (U value-0.0374 BTU/ hr ft² °F).

Methodology

Shading Analysis

Shading obstructs the direct beam radiation exposure thereby cutting down the heat ingress into buildings. In order to determine a baseline above which shading is required, ASHRAE adaptive comfort model is studied which recommends for shading when the Global Horizontal Radiation (GHR) is greater than 315.5 Wh/m² (Climate Consultant 6.0).

Hence, hourly average Global Horizontal Radiation throughout the year is been tabulated as shown in Table 1 and the GHR over 315.5 Wh/m² is highlighted and is plotted over the Sun path diagram to critically shade the periods exposed to high intensity of radiation. The aim of the screen geometry is to cut down this high intense radiation and shade the glazing adequately in major orientations of the design.

Table 1. Hourly average Global Horizontal Radiation of sun with Altitude and Azimuth angle

	7.00		8.00		9.00		10.00		11.00		12.00		13.00		14.00		15.00		16.00		17.00		18.00	
Jan	0.0	5.1 / 114.8	25.2	18.2 / 119.0	419.4	30.7 / 125.4	567.9	42.0 / 135.3	629.6	51.0 / 150.6	596.5	55.7 / 172.4	571.7	54.6 / -163.4	552.2	47.9 / -144.0	563.7	37.9 / -131.0	506.1	26.1 / -122.6	383.9	13.3 / -117.2	183.6	
Feb	0.0	4.1 / 108.7	40.0	17.9 / 112.6	475.1	31.2 / 118.3	633.8	43.6 / 127.3	649.0	54.2 / 142.0	584.2	60.8 / 165.9	533.3	60.6 / -164.7	530.5	53.8 / -141.2	587.1	43.1 / -126.8	632.4	30.6 / -118.0	566.9	17.3 / -112.4	355.6	3.5 / -108.6
Mar	0.0	6.4 / 99.5	132.8	20.8 / 103.1	573.4	35.0 / 108.0	655.8	48.7 / 115.8	614.9	61.2 / 130.1	522.2	69.9 / 159.8	431.6	69.4 / -156.6	462.1	60.2 / -128.5	545.8	47.6 / -115.0	617.1	33.9 / -107.5	604.7	19.6 / -102.7	389.8	5.2 / -99.3
Apr	0.0	10.8 / 87.9	308.2	25.5 / 90.6	597.4	40.3 / 93.8	661.9	54.9 / 98.4	595.4	69.3 / 107.4	458.0	81.8 / 144.5	355.6	77.8 / -122.8	436.0	64.1 / -103.1	528.1	49.6 / -96.4	560.8	34.9 / -92.6	498.9	20.2 / -89.6	287.7	5.4 / -86.9
May	2.9	14.1 / 77.3	427.0	28.6 / 79.0	640.1	43.0 / 79.9	681.2	57.5 / 79.5	598.6	72.0 / 75.5	456.6	85.1 / 36.9	353.6	77.7 / -70.1	443.0	63.5 / -78.6	538.6	49.0 / -79.9	552.2	34.5 / -79.4	464.0	20.0 / -78.1	287.7	5.6 / -76.0
Jun	1.5	14.8 / 70.0	432.3	28.7 / 70.8	622.2	42.6 / 70.1	687.8	56.3 / 66.5	612.9	69.3 / 55.2	483.2	78.5 / 15.1	367.2	74.2 / -44.0	427.2	62.1 / -63.1	544.5	48.5 / -69.0	586.7	34.7 / -70.7	516.4	20.8 / -70.5	324.4	7.0 / -68.9
Jul	0.0	13.6 / 68.5	347.5	27.4 / 69.4	630.3	41.1 / 68.6	676.6	54.7 / 64.9	619.4	67.5 / 54.1	488.2	76.8 / 19.4	359.1	74.2 / -37.1	429.6	62.9 / -59.5	529.4	49.7 / -66.8	550.3	36.0 / -69.1	473.2	22.2 / -69.2	396.3	8.5 / -67.9
Aug	0.0	12.4 / 73.5	359.8	26.6 / 74.9	625.0	40.8 / 75.1	667.7	55.0 / 73.5	614.3	69.0 / 66.9	464.3	80.9 / 34.2	313.0	78.1 / -50.3	401.8	65.0 / -69.8	510.8	51.0 / -74.3	555.2	36.8 / -75.2	499.2	22.5 / -74.6	340.2	8.4 / -72.9
Sep	0.0	12.5 / 83.5	287.9	27.2 / 85.8	525.1	41.9 / 88.1	606.2	56.6 / 90.8	559.9	71.3 / 95.2	479.4	85.6 / 120.6	384.8	78.7 / -100.5	449.8	64.1 / -92.6	536.9	49.3 / -89.4	492.3	34.6 / -87.0	403.3	19.9 / -84.7	212.8	5.3 / -82.3
Oct	0.0	13.0 / 95.6	179.5	27.6 / 99.1	461.6	42.0 / 104.0	517.0	56.0 / 112.1	521.8	68.8 / 129.5	488.9	76.2 / 174.9	455.9	70.6 / -134.2	465.5	58.2 / -114.0	482.9	44.3 / -105.0	422.3	29.9 / -99.8	341.4	15.3 / -96.1	136.4	0.6 / -93.1
Nov	0.0	11.9 / 107.2	139.7	25.8 / 111.7	383.3	39.1 / 118.5	467.9	51.4 / 129.7	514.6	61.1 / 149.5	511.5	65.0 / -179.3	502.2	60.7 / -148.4	477.3	50.9 / -129.1	425.1	38.6 / -118.2	374.3	25.2 / -111.5	237.4	11.3 / -107.0	66.4	
Dec	0.0	8.7 / 114.2	88.1	21.9 / 118.8	425.0	34.4 / 125.9	542.2	45.5 / 136.9	605.4	53.9 / 154.2	555.1	57.5 / 178.2	547.8	54.7 / -157.1	556.3	46.8 / -138.9	506.5	36.0 / -127.1	448.3	23.6 / -119.6	312.8	10.5 / -114.7	98.6	

The *Jaali* screen configuration varies for different altitude and azimuth of sun position at various times of the year. Thus, the altitude and azimuth for every hour was optimized and respective Horizontal Shading Angles (HSA) and Vertical Shading Angles (VSA) were tabulated. The required HSA and VSA highlighted in the sun path diagram shows that the critical area is shaded as shown in fig.4. The screen geometry is now devised for the respective HSA and VSA to achieve optimum shading.The depth of the screen was kept constant at 5cm and the module sizes were devised for uniform size of (0.5 x 0.5) m.

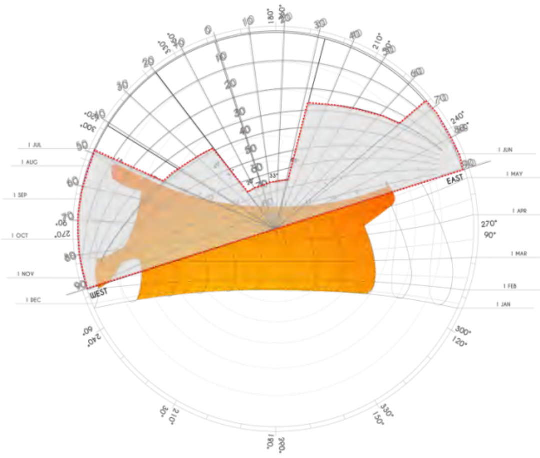


Figure 4. Azimuth and Altitude plotted Over Shadow Angle Protractor

Optimum screen configuration for -17.5° North orientation

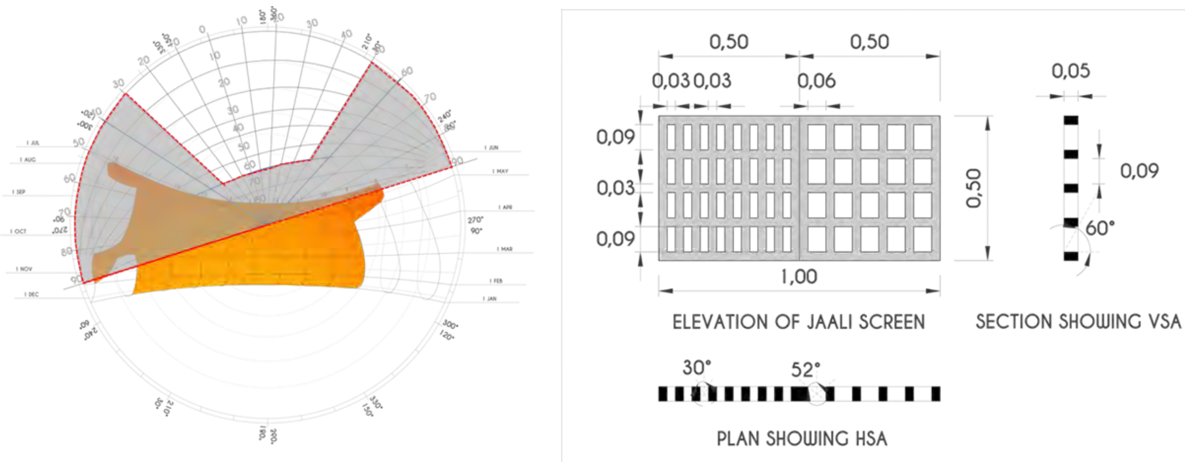


Figure 5. HSA and VSA plotted for -17.5° North orientation and the devised optimum screen configuration

Optimum screen configuration for -17.5° East orientation

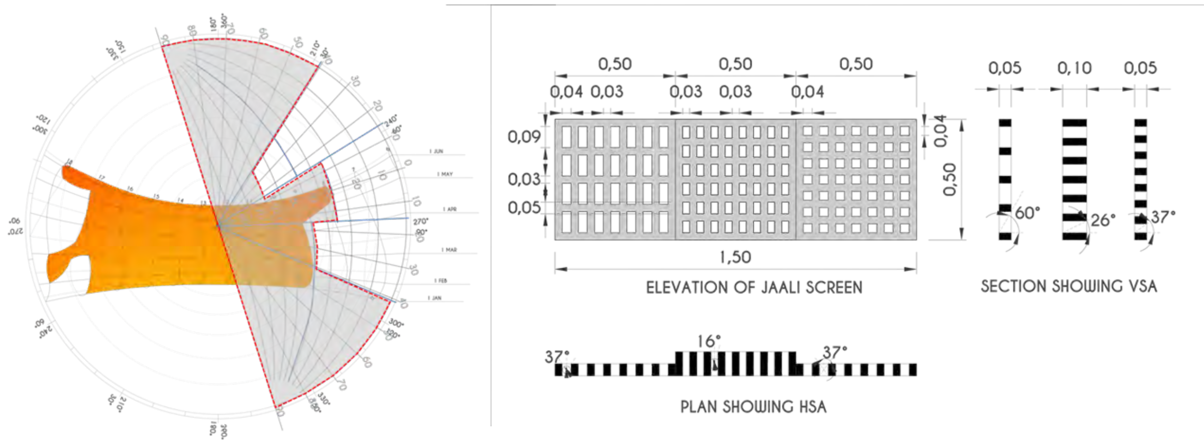


Figure 6. HSA and VSA plotted for -17.5° East orientation and the devised optimum screen configuration

Optimum screen configuration for -17.5° South orientation

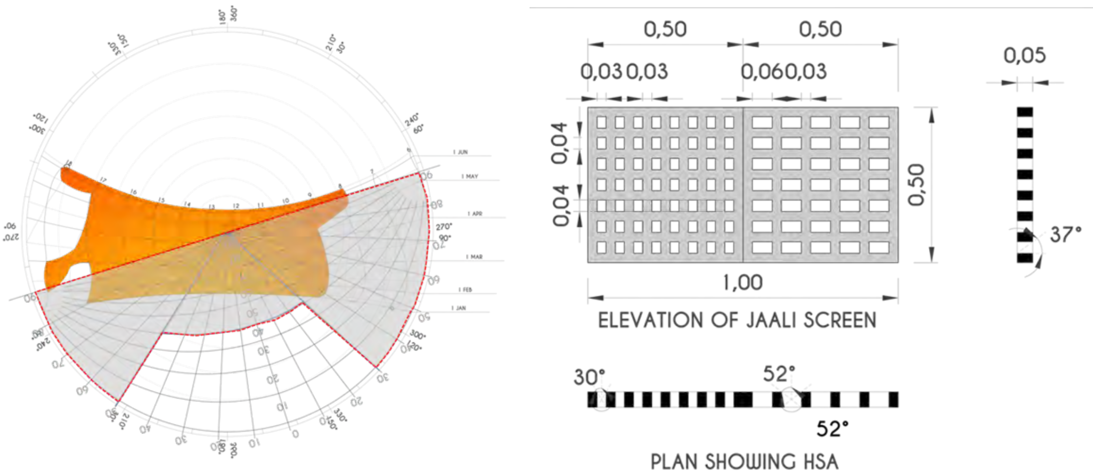


Figure 7. HSA and VSA plotted for -17.5° South orientation and the devised optimum screen configuration

Optimum screen configuration for -17.5° West orientation

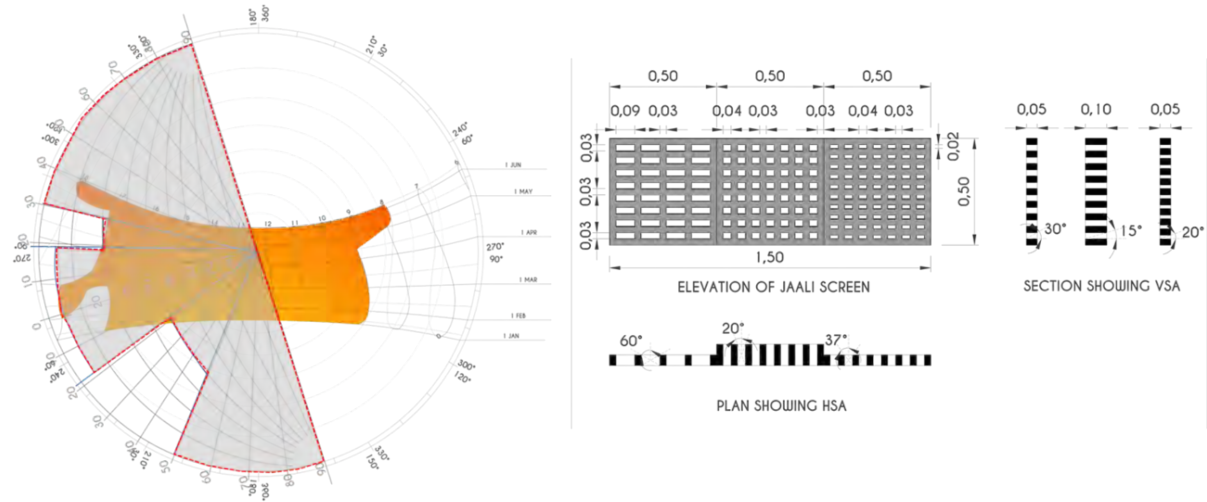


Figure 8. HSA and VSA plotted for -17.5° West orientation and the devised optimum screen configuration

Results

Shading calculation

The simulation results for shading the major orientations with *Jaali* screens are shown as follows,

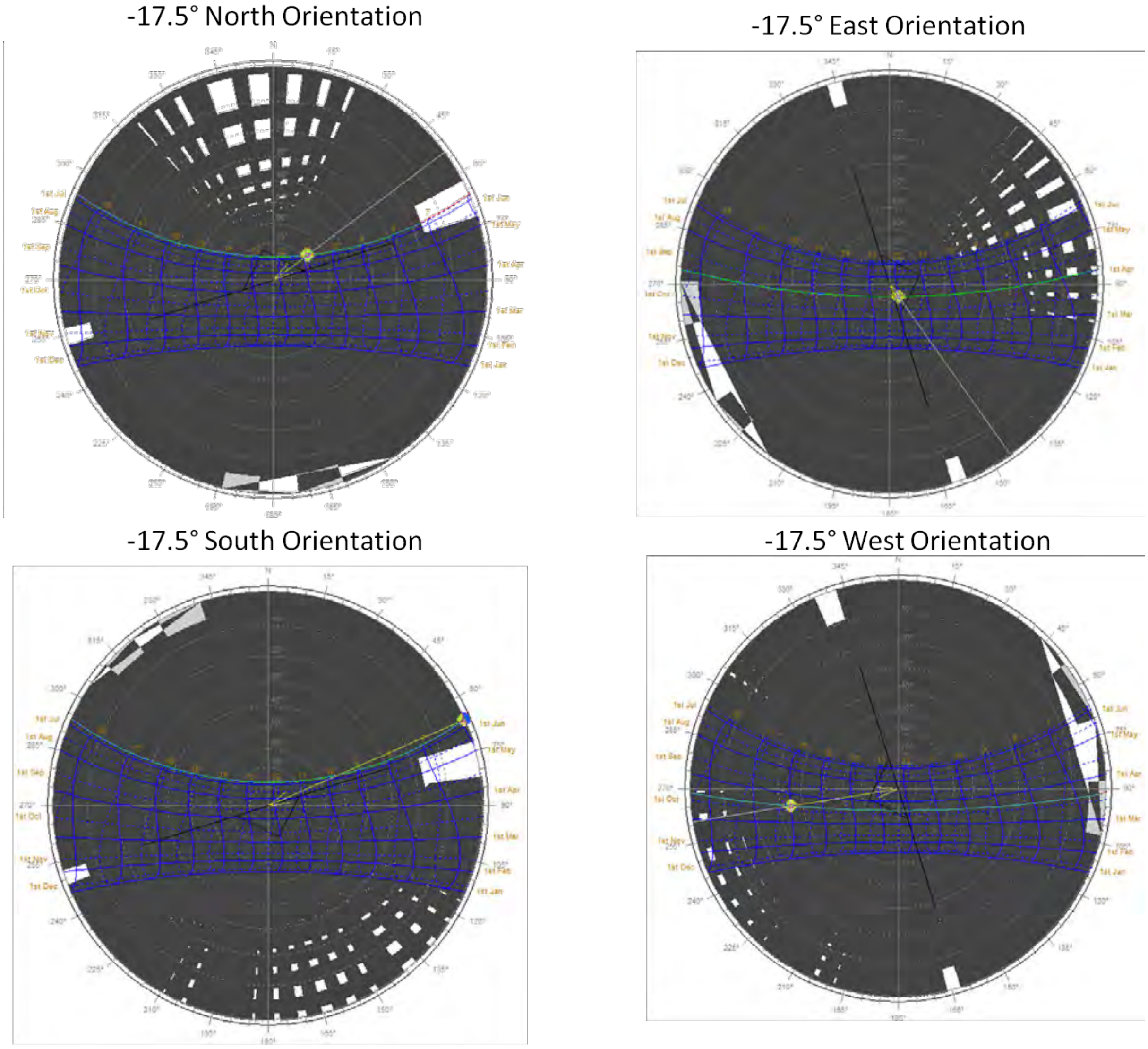


Figure 9. Shading Calculation of the screen for four major Orientations

Lighting Evaluation

Minimum Daylight requirements as per ECBC is: For a non-residential building having less than 3 stories above the ground shall have a minimum of 45% of its floor area exposed to daylight in range of 100 – 2,000 lux for at least 90% of the year (USAID Eco III Project, Energy Conservation Building Code 2017 - User Guide, Bureau of Energy Efficiency). The design is evaluated to meet the ECBC daylight requirements.

The evaluation is done for 15th of every month of a year in two time intervals (i.e., 10.00 am and 3.00 pm). The maximum, minimum and average illuminance for every month is tabulated as shown in Table2.*(UDI is defined as the annual occurrence of daylight between* ***100 lux to 2,000*** *lux on a work plane. This daylight is* ***most useful to occupants****, glarefree and when available, eliminates the need for artificial lighting.)*

Table 2. Maximum, minimum and average illuminance for every month

ORIENTATION	Month	January		February		March		April		May		June		July		August		September		October		November		December	
	RAD Illuminance (Lux)	10	15	10	15	10	15	10	15	10	15	10	15	10	15	10	15	10	15	10	15	10	15	10	15
North Jali	Average	445	445	615	641	606	593	605	646	318	388	327	394	327	310	329	371	334	296	323	266	300	242	446	433
	Minimum	133	180	201	225	260	265	222	233	145	159	142	149	145	158	144	135	154	137	150	122	132	120	132	116
	Maximum	1866	2810	2094	1833	1996	1920	1929	1773	992	1080	975	1137	1181	1095	1108	1122	1194	1035	1139	934	1044	852	1926	1252
East Jali	Average	268	335	509	546	555	558	689	541	245	314	272	296	232	223	267	302	245	210	242	189	217	171	278	436
	Minimum	122	141	159	257	282	287	283	285	105	125	133	123	105	117	134	122	122	127	113	115	127	103	132	131
	Maximum	907	1880	1425	2345	1526	2302	1611	2221	900	1646	984	1522	978	975	949	1585	1054	927	1019	828	927	768	923	2385
South Jali	Average	362	327	744	546	665	520	583	530	286	356	298	364	286	271	210	339	292	259	285	235	263	210	363	320
	Minimum	152	160	474	327	221	190	208	188	127	219	136	218	150	125	132	155	141	122	139	111	125	102	143	168
	Maximum	1230	984	1799	1633	1667	1796	1779	2010	960	1544	1040	1652	1037	974	937	1454	1073	953	1023	862	957	773	1221	944
West Jali	Average	399	377	625	910	656	905	673	868	372	360	390	356	306	290	385	354	313	275	303	247	280	225	387	364
	Minimum	158	171	292	501	316	500	332	453	156	189	165	178	159	148	150	195	166	141	152	124	145	114	186	182
	Maximum	1669	1327	2266	2213	2370	2123	2409	1964	1587	1140	1674	1090	1172	1079	1667	1123	1177	1024	1123	944	1034	845	1590	1329

The worst case scenario is taken during the time with highest sky cover, during which thedaylight availability is considerably reduced. For the climate of Trichy, the worst case scenarios occur during the month of october which has highest sky cover up to 68% (Climate Consultant). The values are simulated for Oct 12 & 13 which experiences 100% sky cover between 9am to 5pm.

Table 3.Illuminance for Worst case Scenarios in a year

WORST CASE SCENARIO					
ORIENTATION		NORTH JALI	EAST JALI	SOUTH JALI	WEST JALI
TIME		OCT- 12, 1.00PM	OCT 13, 1.00PM	OCT 13, 12.00 NOON	OCT 12, 10.00AM
ILLUMINANCE	AVERAGE	366.42	270.04	333.91	333.91
	MINIMUM	141.74	139.7	148.19	148.19
	MAXIMUM	1285.96	1148.19	1230.89	1230.89

Observations and Conclusion

Shading calculation for optimum screen configuration for all four major orientations in fig.9 shows that the windows are shaded throughout the year for the recommended Global Horizontal Radiation plotted on the sun path diagram.

These *Jaali*screens then are tested for lighting through analysis for different months on all four major orientations. The results in Table 2 show that all the tabulated values lie within the range of 100-2000lux which is considered as the useful daylight, glare free while eliminating the need for artificial lighting. In addition to the monthly average lighting analysis, the worst case scenario of a year is taken into consideration. Table 3 shows that all four orientations in spite of being shaded with *Jaali* screens receive the desired lighting between 100-2000lux as per ECBC recommendation. Hence, throughout the year the classroom spaces receive continuous daylight while the windows are being sensibly shaded with *Jaali* screens.

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Open windows for natural ventilation and outdoor noise reduction in tropical climates

Christina Mediastika[1], Luciana Kristanto[1], Juliana Anggono[2], Fefen Suhedi[3], Hariyati Purwaningsih[4]

[1]Department of Architecture, Petra Christian University, Surabaya 60236, Indonesia, eviutami@petra.ac.id
[2]Department of Mechanical Engineering, Petra Christian University, Surabaya 60236, Indonesia
[3]Research and Development Centre for Housing and Settlement, Ministry of Public Works and Housing, Bandung 40622 Indonesia
[4]Department of Material Engineering, Institut Teknologi Sepuluh Nopember, Surabaya 60111 Indonesia

Abstract: 'Real' open windows for buildings in tropical climates were studied. It focused on the window degree of openings and window orientation toward the noise source. The window type to be tested was top-hung shutter type only, based on multitasking duty between permitting airflow and noise blockage. The top-hung open window with a uPVC frame was tested of 3 orientations, i.e. perpendicular, oblique 60°, and 90°. The degree of openings was tested on 0° (closed), 5°, and 10°. Laboratory tests according to ASTM E90-09 were conducted to determine transmission loss (TL) & ASTM E1332-90 was referred to calculate the outdoor-indoor transmission class (OITC). Later, finite element analysis using COMSOL 5.0 was conducted to study the sound contour developed around the models. The study revealed that window orientation has little effects of noise reduction. Here, a 'real' open window is still not capable of blocking noise into the living spaces. However, when the open window was closed, perpendicular orientation offered higher OITC compared to the oblique ones. Thus, a perpendicular orientation is more recommended to reduce noise.

Keywords: natural ventilation, tropical climate, open window, top-hung window, OITC

Introduction

Buildings in tropical climates encounter totally contradictory requirements between using lightweight materials and open envelopes for natural cooling and using weighty materials for environmental noise blockage. 'Real' open windows were studied here. The term real open window is used to separate it from a partially open double layered window suggested for ventilation and noise abatement (Ford and Kerry, 1973 and Burrati 2002 & 2006), but impractical for tropical climates. In a tropical warm-humid climate, a passive cooling by means of open windows shall have an open area of at least 5% of the ventilated floor area (SNI 03-6572-2001). As an example, a 15 sqm floor area will need 0.75 sqm of openings. With a partially open doubled layered window with say a maximum gap of 0.2 m, the room will need window as wide as 3.75 m, which is considered impractical for 15 sqm floor area only.

The existence of real open windows where the use of mechanical ventilation is mostly at night time due to energy saving issue and even for public buildings with the energy savings in mind is significant. A real open window that may conquer noise intrusion is a later issue. Openings placement on a wall will reduce the wall sound insulation property. As in general glass walls are thinner than masonry walls, the sound insulation property decreases accordingly (Quirt, 1981; Quirt 1982; Garg et al, 2011). Earlier studies have indicated that in warm temperature, laminated glass offered the best STC and TL contour compared to monolithic and tempered glass. But the OITC was low due to a coincidence dip developed at 125 Hz (Mediastika et al, 2015; Mediastika et al, 2016a). In overall, the use of glass in a temperature warmer than the ASTM E90-09 was suggested to be slightly thicker. In warm temperature, the STC and OITC of glass are 1 to 2 levels lower (Mediastika et al, 2015; Mediastika et al, 2016a).

Besides the specific glazing type of windows that will work for warm temperature, an earlier study has also recommended a particular framing material for conquering noise intrusion by an open window. When the open window was closed, a uPVC frame offered the best insulation. A laboratory test of timber, Aluminium, and uPVC proved that insignificant sound insulation was gained when the windows were opened (Mediastika et al, 2016b). In the study reported here, the orientations of glass windows to the noise source were tested in the laboratory of 1 to 1 scale, analysed, and verified using COMSOL 5.0 Multiphysics regarding the sound contour developed around the specimen.

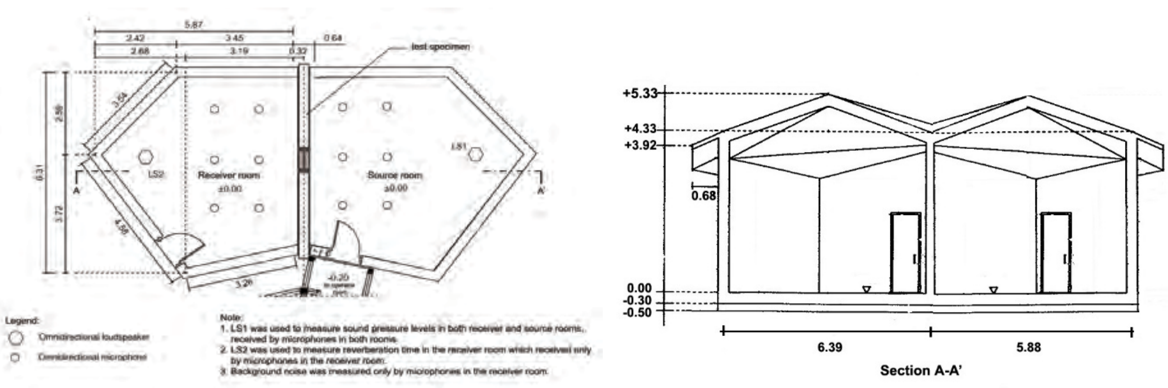
Methods

The study reported here is a series of empirical research, some have been reported and published, i.e. study on insulation properties of several glass types and study on the insulation properties of framing material for glass windows. The studies were conducted comprehensively using the following methods.

- Selection of glass types to be tested based on glass types commonly used for building facades in Indonesia (Anonymous, 2015). The tested specimens were monolithic, tempered and laminated. They were tested using ASTM E90-09 with a specific condition was applied based on Annex.3 on the use of the composite wall system (Figure 1). Equipment used for testing was Bruel & Kjaer 2- channel building acoustic system consisting of power amplifier type 2734 and 4292 omnidirectional loudspeakers as the sound source, 2 pieces of type 4189 omnidirectional microphones as the sound sensor, and 2-channel handheld analyzer type 2270 as the main instrument data processor. The microphones were calibrated using type 4231 prior to the testing stage. The room temperature was set at 27°C to 32°C as a replica of the average daily temperature of tropical climate (Feriadi & Wong, 2004; Hariyanto, 2005; Karyono, 2000). The first stage of glass testing showed that laminated glass types offered the best TL contour and STC, but not of the OITC due to a coincidence dip at 125 Hz.
- The next stage was to test frame materials suitable for openable windows and that are commonly used in Indonesia, which is timber, Aluminium, and uPVC. They were tested using ASTM E90-09 with a specific condition were applied based on Annex.3 with laboratory equipment as were used during the first testing stage. The second testing stage concluded that with rubber strips and sealant, a uPVC frame offered the best insulation for both fix and open windows when the open window was closed.
- The third testing stage reported here was to study the orientations of glass window toward the noise. It is perpendicular, oblique 60° and oblique 90° (Figure 2). A particular glass window type; top-hung; was selected due to shutter position that may

block noise pathways. Glass type, glass dimension, and frame material were the fix variables, which is monolithic glass, 10 mm thickness, 800 mm x 1200 mm, and uPVC frame (Figure 2). With the early testing stages have indicated the best insulation offered by a glass type and a frame material, glass type and frame material used at this stage were based only on resources limitation and the ease of installation. The testing method and equipment employed at this stage was similar to those of the earlier stages. The temperature and relative humidity (RH) during the testing period were 25°-26°C and 80% - 90%.

- In this study, the orientations of the open windows were assigned as the variable to be tested, but the window style was determined as a fixed variable. It was a top-hung open window style. The top hung style was selected based on the capability to permit ventilation and the possibility of noise blockage by the shutter position (De Salis, et al, 2002, Figure 2). Gao and Lee (2010) determined that the top-hung window type was the worst in natural ventilation compared to end-slider and side-hung. But these 3 types were chosen by Gao and Lee as the possible types for natural ventilation only. The lowest ventilation rate by the top- hung window was caused by the shutter position that blocked the airflow. However, still, a top-hung window was capable of supplying natural ventilation (Coley, 2008) when be compared to the 'non-real' open window (Ford and Kerry, 1973 and Burrati 2002 & 2006). Another window type with similar shutter position to top-hung, such as bottom-hung was not tested due to the limited resources. Besides, the bottom-hung window is rarely used in Indonesia caused by the less accessible handle and latch.
- The top-hung window was tested at 3 degrees of openings, i.e. 0° (closed), 5°, and 10° (Figure 3 and 4). The closed condition was tested to study whether the gap between frame and the shutter has an effect on noise intrusion due to the window position. The 10°was selected as the maximum degree of opening for safety reason and ease of people movement along the corridor or space by the window.
- The OITCs were calculated from the TL of 1/3 octave band frequency according to ASTM E1332-90.
- The test specimen was then modelled in a finite element analysis using COMSOL 5.0 Multiphysics to study the sound contour around the specimen to confirm the finding of the laboratory test.



(a) (b)

Figure 1. Plan of the testing rooms and the equipment layout (a) and section (b).

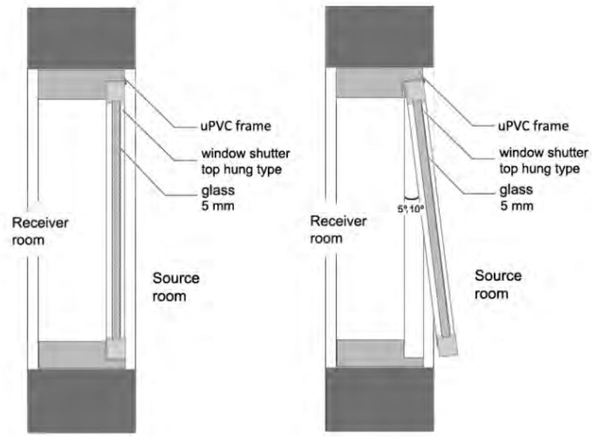
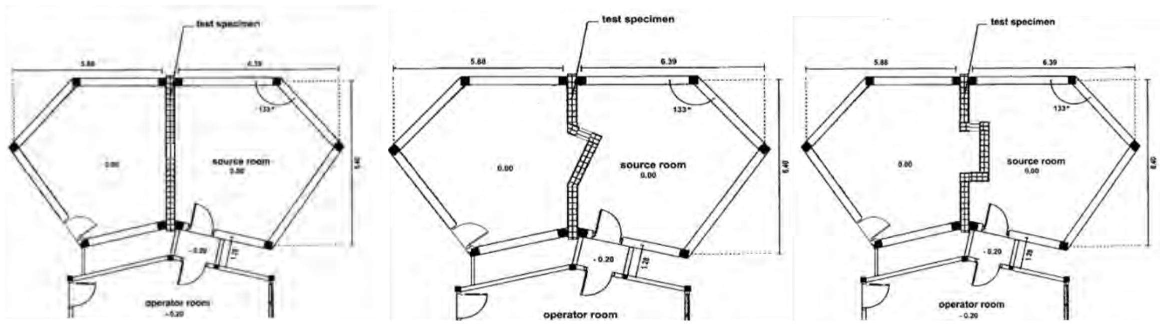
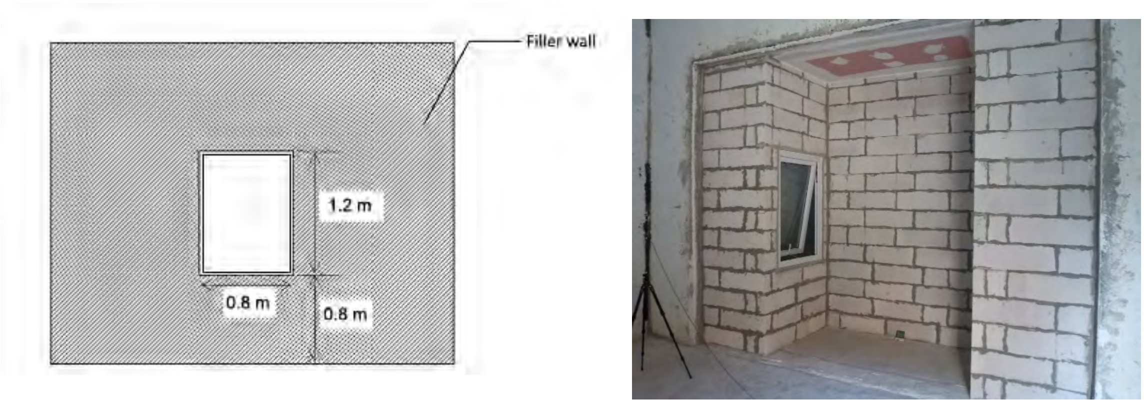


Figure 2. Section showing the degree of openings of the window shutter; 0° (a) and 5° and 10° (b).



(a) (b) (c)

Figure 3. Plan of the window specimen's orientation: perpendicular (a), oblique 60° (b), and oblique 90° (c).



(a) (b)

Figure 4. Schematic front view of perpendicular composite wall (a) and view of the oblique 90° composite wall specimen from the receiver room during construction (b).

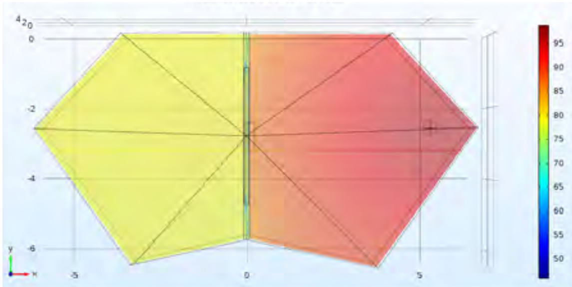
Findings and Discussion

A series of laboratory test has been conducted to see the effect of a top-hung open window in blocking noise. The result of the laboratory test is compiled in Table 1. When the open windows were closed (open 0°), the OITC of perpendicular orientation were higher than the oblique ones. But when they were opened, the OITC values were similar regardless orientations, either perpendicular or oblique and regardless degrees of obliqueness. These findings strengthen earlier studies that larger degree of openings permits noise intrusion easier (De Salis, et al, 2002). Both the oblique that seemed to have a larger open area and the perpendicular that seemed to have a smaller open area due to the shutter positioned parallel to noise performed similar OITC.

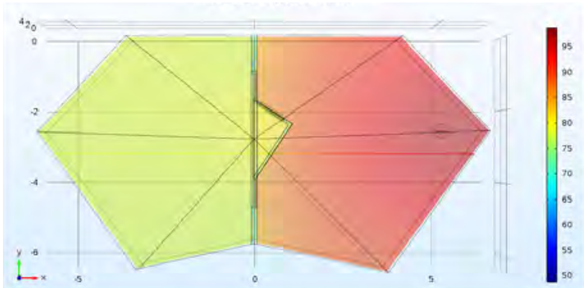
Later, the laboratory findings, which showed that insulation values of either oblique 60 (or 90 (were similar were confirmed using finite element simulation to see the sound contours developed around the openings. Figure 5 shows that both orientation results in similar sound contour, sound dispersion, and sound levels. It means that either 60° or 90° obliques did not offer different insulation values to noise. It is more interesting to study the sound transmission loss (TL) contour of the specimen shown in Figure 6. Here, all closed open windows drawn similar contours except the oblique, which indicated a coincidence dip at 80 Hz. It was predicted not due to the gap position between the frame and the shutter, but due more to the presence of an angle of the oblique wall. However, the finite element analysis showed that the sound dispersion developed around the openings is similar, means that the wall's angle did not affect the sound contours. One thing should be remembered, simulation by using finite element does not consider the sound frequency. It is only the sound intensity that is taken into account. Thus, the condition of coincidence dip was not represented in the simulation. A further test conducted in a laboratory with larger dimension to accommodate low sound frequencies pathways, is significant to confirm this finding.

Table1. Transmission loss and STC/OITC of perpendicular, oblique 60°, and oblique 90°.

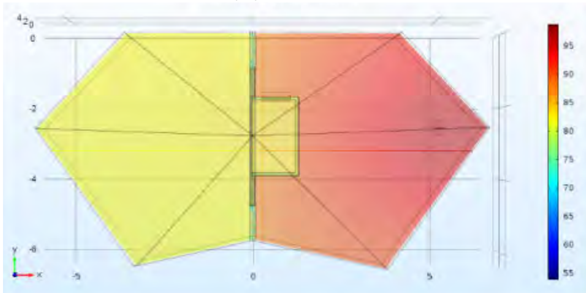
1/3 Octave band frequency (Hz)	Perpendicular			Oblique 60°			Oblique 90°		
	Open 10°	Open 5°	Open 0° (closed)	Open 10°	Open 5°	Open 0° (closed)	Open 10°	Open 5°	Open 0° (closed)
80	18,0	19,0	31,0	18,0	19,0	14,0	18,0	19,0	14,0
100	16,0	18,0	29,0	16,0	18,0	24,0	16,0	18,0	24,0
125	9,0	9,0	21,0	5,0	6,0	17,0	5,0	6,0	17,0
160	4,0	6,0	21,0	7,0	9,0	20,0	7,0	9,0	20,0
200	4,0	7,0	20,0	4,0	5,0	18,0	4,0	5,0	18,0
250	5,0	8,0	21,0	6,0	8,0	20,0	6,0	8,0	20,0
315	6,0	9,0	22,0	7,0	8,0	21,0	7,0	8,0	21,0
400	3,0	7,0	22,0	4,0	7,0	22,0	4,0	7,0	22,0
500	3,0	6,0	23,0	3,0	7,0	23,0	3,0	7,0	23,0
630	4,0	6,0	27,0	4,0	6,0	24,0	4,0	6,0	24,0
800	4,0	5,0	29,0	5,0	6,0	25,0	5,0	6,0	25,0
1000	4,0	5,0	31,0	5,0	6,0	27,0	5,0	6,0	27,0
1250	4,0	6,0	34,0	5,0	6,0	30,0	5,0	6,0	30,0
1600	4,0	6,0	35,0	5,0	6,0	32,0	5,0	6,0	32,0
2000	5,0	6,0	33,0	5,0	7,0	33,0	5,0	7,0	33,0
2500	6,0	8,0	31,0	7,0	8,0	30,0	7,0	8,0	30,0
3150	7,0	10,0	31,0	7,0	11,0	31,0	7,0	11,0	31,0
4000	6,0	11,0	33,0	7,0	11,0	33,0	7,0	11,0	33,0
OITC	5	7	25	5	7	23	5	7	23



(a)

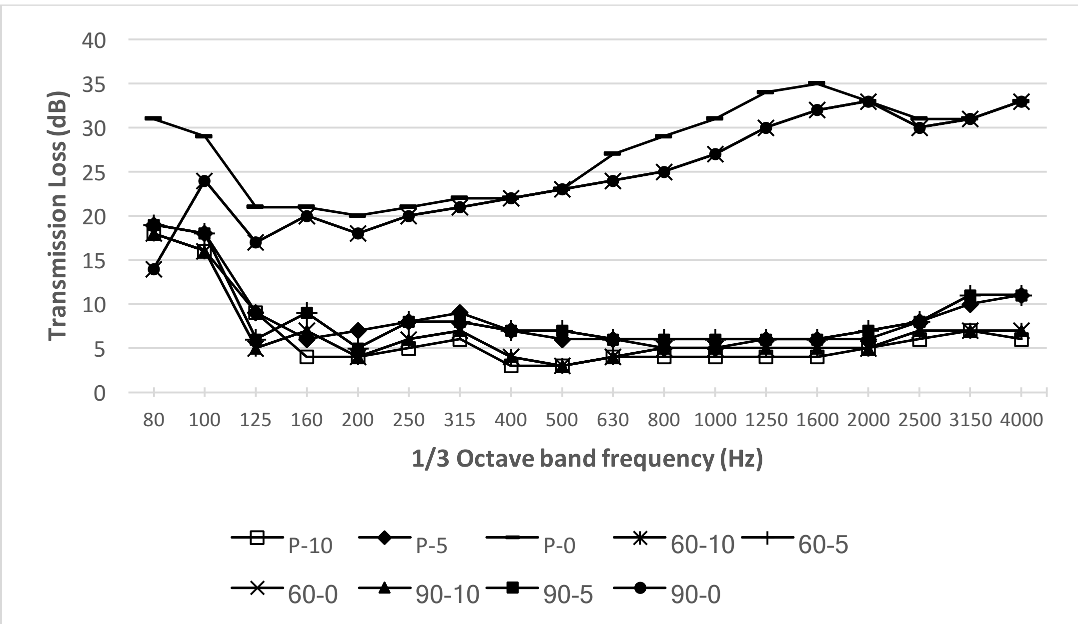


(b)



(c)

Figure 5. Sound distribution and contour developed around the perpendicular open window (a), oblique 60°, (b) and oblique 90° (c).



Legend: P is perpendicular orientation, 60 is oblique 60°, 90 is oblique 90°, 10, 5 and 0 is the degree of openings

Figure. 6. TL contour of the tested specimen.

Conclusion and recommendation

The laboratory test and the computational simulation were in good agreement. The laboratory test showed a 'real' open window of a top-hung style offered OITC as low as 5, regardless window orientations. It was supported by the COMSOL simulation that showed TL contours developed around the model were of high noise levels. The offered OITC value is considered too small to reduce environmental noise in the residential area, which might reach up to 75 dB (Iswar, 2005). But when the open window was closed, perpendicular orientation resulted in higher OITC compared to the oblique ones. Five degrees of openings resulted in OITC of roughly 2 points higher than the 10°. For natural ventilation purposes in tropical climates, 10° of openings may be preferable. But the users should be aware of the low OITC offered by 10° of openings. In overall, a 'real' open window positioned perpendicular to noise source is suggested to conquer noise whenever it is open or closed. A 'real' open window is still incapable of providing significant noise reduction whatsoever.

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Design to Thrive

Window use: Potential and challenge to more energy-efficient residential buildings in hot-humid climates

Pimolsiri Prajongsan[1]

[1] Faculty of Architecture, Silpakorn University, Bangkok, Thailand,
prajongsan_p@silpakorn.edu

Abstract: Window use is a challenging issue for mixed-mode residential buildings to achieve energy efficiency. According to 216 residents from 15 condominiums in Bangkok, more than 75% of the respondents operate a/c in their bedrooms during nighttime, regardless of external climatic conditions. In this study, four modes of window use i.e. *no ventilation, all-day ventilation, day-time ventilation and evening-time ventilation* and their effect on a bedroom's cooling energy use were investigated using the EnergyPlus function in DesignBuilder version 5.0.1.024. The way windows are used was found to have an effect on the bedroom's cooling energy use. Airflow rate and indoor-outdoor temperature difference were key parameters to determine such effect. In this particular case, the bedroom with *evening-time ventilation* had the lowest annual cooling energy, while that with *day-time ventilation* had the highest. The differences of cooling energy use could reach 13.0-17.6kWh per year, depending on the bedroom orientation. These results indicate that residents' behavior is crucial for determining the successfulness of mixed-mode residential buildings to achieve energy efficiency and window use could be employed as a promising post-occupancy strategy for reducing the buildings' electricity consumption due to cooling systems.

Keywords: window use, post-occupancy, mixed-mode ventilation, residential buildings, hot-humid climates

Introduction

More than 2,300 residential buildings, or '*condominiums',* which accumulate 340,000 residential units have been built in Bangkok metropolitan area since the last ten years (Bangkok metropolitan administration, 2015). These condominiums are mostly the change-over type of mixed-mode buildings - natural ventilation and cooling systems are employed in the same space, but at different times. Operable window(s) and split-type air conditioner(s) are installed in each residential units and they are controlled by the residents.

For a naturally ventilated residential building in hot-humid climates, architectural characteristic is a significant parameter to determine the success of the building in employing comfort ventilation as a passive tool to maximize its resident comfort. To achieve this, architects are suggested to concern on key issues including spacing among buildings, figure and layout of a building regarding to its environment as well as the building's opening design (Prianto et al., 2002; Liu et al., 2014; Zhou et al., 2014). On the contrary, not only architectural characteristic, but also occupants' behavior is crucial for assuring the successfulness of a mixed-mode building in terms of its energy efficiency. This is particularly true for window use as it is the most uncertain and less predictable parameter that affects a building's energy use due to cooling system (Nicol et al., 2004; Rijal et al., 2007; Ackerly et al., 2011; Liping et al., 2015).

Window use is found to depend on the occupants' perception and expectation of comfort, which are mainly related to outdoor climatic condition, indoor thermal condition as well as time of the day (Yun et al., 2008; Andersen et al., 2009; Huang et al., 2014). In this study, the residents' behavior on window use and its effect on a building's cooling energy use were investigated. Window use was hypothesized to have an effect on a building's indoor air temperature, heat balance and, thus cooling energy use, which in turn could be helpful for a mixed-mode residential building to achieve more energy efficiency.

Methodology

In this study, typical characteristics of high-rise condominiums built in Bangkok metropolitan area since the last 10 years were surveyed. Then the residents' behavior on air-conditioner (a/c) and window use was studied using questionnaire and short-interview. Finally, such residents' behavior was investigated in terms of its effect on a building's energy use for air-conditioning systems using EnergyPlus 8.5 built in DesignBuilder version 5.0.1.024.

High-rise condominiums and the residents

In 2016, the architectural characteristics of 72 high-rise condominiums those situated within 500m from Bangkok mass rapid transit stations were surveyed. The condominiums were middle to upper-middle class, which were developed by six private developers who continually launch high-rise condominium projects since the last 10 years. It was found that all the condominiums are double-loaded i.e. a building with an internal corridor that provides access to units on both sides. Most of the residential units are single bedrooms with floor area ranging from 26m^2 to 50m^2 and almost all the units have single-sided ventilation. In this study, one of the three layouts of single bedroom units commonly found from the survey was employed as a studied building (Figure 1).

The behavior of the residents in these condominiums were also investigated. There were 216 questionnaires collected from the residents of single bedroom units from 15 condominiums. It was found that most of the units are occupied by 1-2 persons (81%, N=216). During weekdays, the units are occupied mostly in the evening and at night (18:00-22:00hrs in the living room and 22:00-7:00hrs on the next day in the bedroom), while most of the living rooms are occupied all day during weekends. In terms of a/c use, more than 98% and 89% (N=216) of the respondents installed a/c in their bedrooms and living rooms, respectively. Most of them operate a/c in their bedrooms at night, either in summer or winter season. Only a small number of the respondents use their windows on weekdays and weekends (35.6% and 38%, N=216, respectively). However, these respondents use their windows in different ways - some respondents (9.1%, N=22) leave their windows open all-day (7:00-20:00hrs) during weekdays when they do not occupy the unit to use incoming fresh air for reducing undesired odour and humidity found indoor, while the others (40.9%, N=22) open their windows during evening-time to flush out the hot air accumulated indoor before operating a/c.

Simulation setup

A studied building was formulated as a 20-floors building (WxLxH=16mx70mx60m), according to typical characteristics of high-rise condominium found from the survey (Figure 1). The building was a double-loaded corridor type with single bedroom units situated on both sides on every floor. A single-sided ventilated unit on floor-10 was chosen as a studied unit and its bedroom (11.75 m^2) was used here for investigating the effect of different window uses on the bedroom's cooling energy. The building external wall was precast concrete (U-factor with air film = 4.565Wm^{-2}.K) with 2.88m^2 fixed tempered laminate glazing

(12mm-thick, U-factor with air film=6.108$Wm^{-2}.K$, SHGC=0.559) and operable window (a top-hung window with maximum operable area of approximately 20% i.e. about 0.14m^2).

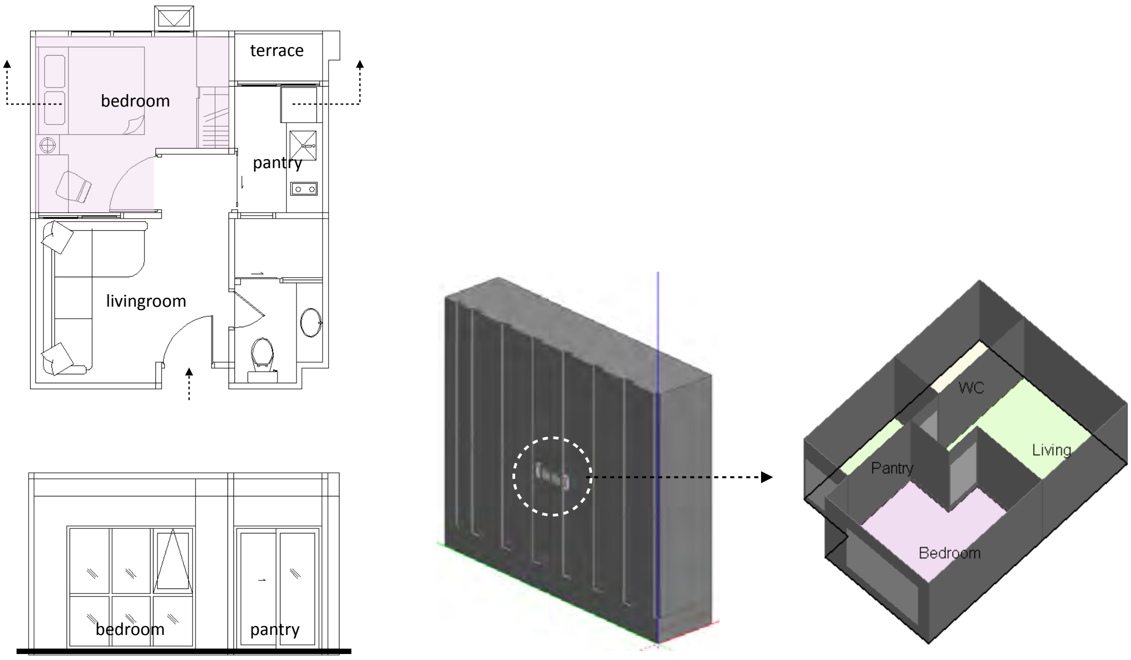

Figure 1. The studied unit: (left) layout and elevation towards the external wall, (middle) the location of the studied unit in the studied building and (right) the simulated studied unit.

In order to investigate the effect of window use on the bedroom's cooling energy use, a/c in the bedroom was assumed, according to the survey, to be operated daily during 22:00-7:00hrs on the next day. The doors between the bedroom, the living room, the pantry and the terrace were assumed to be open during the time when the window was open. Four modes of window use in this study involve:

- Mode A (*no ventilation*): The window is closed at all time.
- Mode B (*all-day ventilation*): The window is open all day (7:00-22:00hrs.).
- Mode C (*day-time ventilation*): The window is open during daytime (7:00-17:00hrs.).
- Mode D (*evening-time ventilation*): The window is open during evening-time (17:00-22:00hrs).

Default Bangkok weather data was employed throughout the study. The a/c set-point temperature was assumed as 26 degree Celsius. External infiltration was assumed as '*medium crack*' when a/c was off and mechanical ventilation was assumed as 0.56 $l.s^{-1}.m^{-2}$ when a/c was on, according to the minimum requirement for fresh air by Thailand Building code. Internal heat gains included occupancy (90W/person, 2 persons were assumed in the bedroom, occupied period was during 22:00-7:00hrs on the next day); and lighting (2.6 $W.m^{-2}$, during occupied period). Wind pressure coefficient (C_p) used in this study was calculated using the external CFD function of DesignBuilder software.

In total, there were 48 simulations performed in this study. These involve two main stages of the study: i) 32 simulations for investigating the effect of four different window uses on indoor air temperature and external heat gain of the studied bedrooms facing to four main orientations i.e. South, North, East and West during two period i.e. summer typical day (in May) and winter typical day (in November); and ii) 16 simulations for investigating the effect of four different window uses on the annual cooling energy use of the four-oriented bedrooms.

Results and discussions

According to the simulations, the effect of four window uses on the bedroom’s air temperature and heat balance due to external air during typical summer and winter day as well as the effect on the bedrooms’ annual cooling energy use were revealed.

Effect of window uses on indoor air temperature

Air temperatures in the four-oriented bedrooms with four window uses were investigated. Figure 2 illustrates the results of hourly air temperature (T_a) in the bedrooms on the chosen summer and winter typical day against the hourly dry-bulb temperature (T_{out}).

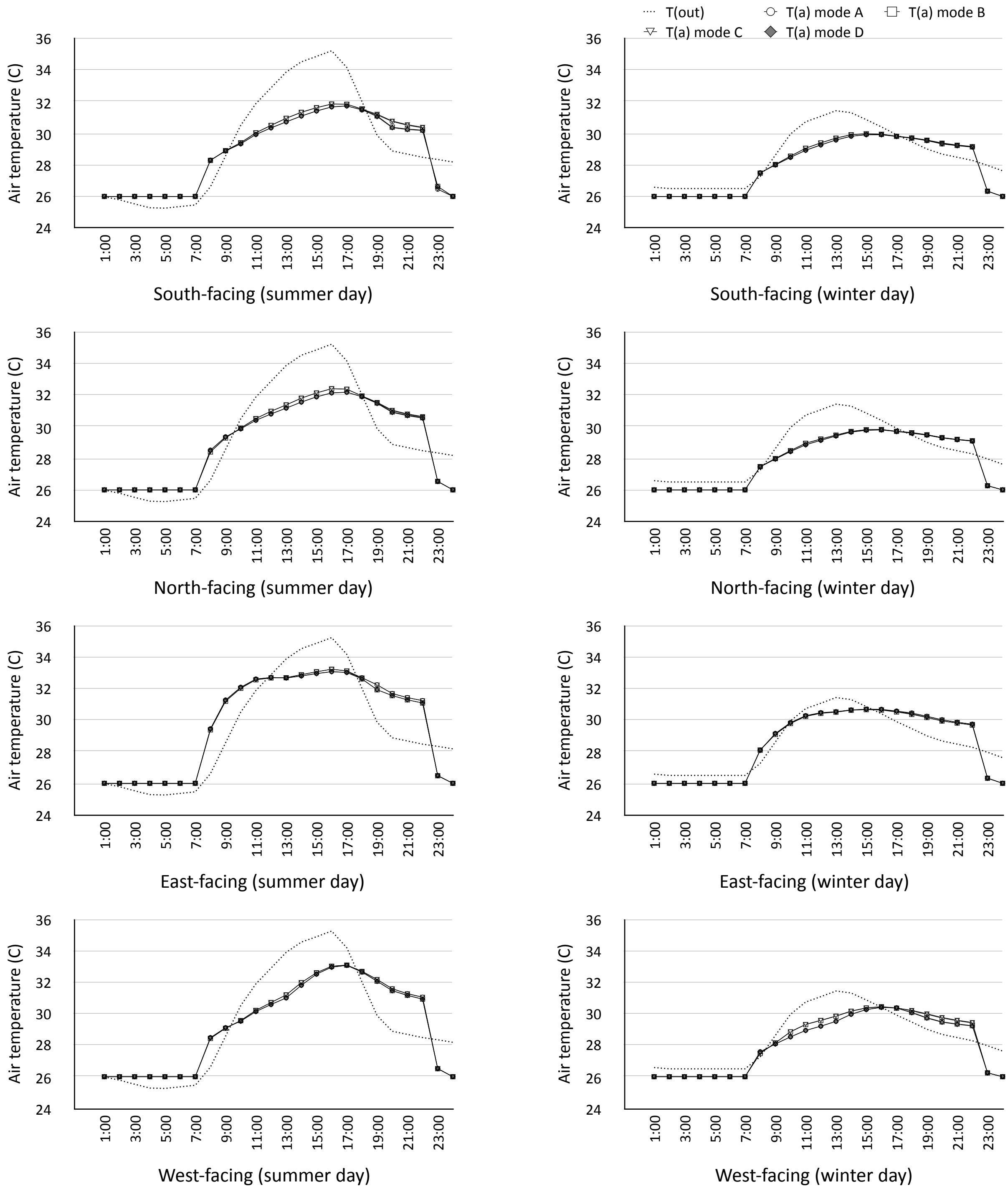

Figure 2: Hourly air temperature (T_a) in the studied bedroom with four modes of window use.

Indoor air temperature (T_a) in the bedrooms was found depending greatly on the rooms' orientation regarding to the sun path. Except for a/c period, T_a in South-, North- and West-facing bedrooms with different window uses all started to rise with the increase of T_{out}, reaching its maximum during 15:00-17:00hrs on the summer day and 14:00-16:00hrs on the winter day. Then it begun to gradually drop in the evening. Differently, T_a in East-facing bedrooms started to rise rapidly after 7:00hrs and stayed stably high throughout the day. It was also found that T_{out} was lower than T_a for all cases in the evening i.e. 18:00-19:00hrs onwards on the summer day and 16:00-18:00hrs on the winter day.

Also, different window uses were found to have a slight effect on the bedroom T_a. At 22:00hrs before the a/c was about to start, T_a of all the bedrooms with '*evening-time ventilation*' and '*all-day ventilation*' were slightly lower than those of the bedrooms with '*no ventilation*' and '*day-time ventilation*', particularly on the summer day. This was because the incoming air with relatively lower temperature may flush out the hot air accumulated indoor and thus help reducing the bedroom T_a. Although the air temperature differences among these bedrooms with different window uses were small i.e. 0.1-0.2 degree Celsius, but the effect of window use on the bedroom T_a was revealed.

Effect of window uses on heat gain

External airflow rate and heat balance of the studied bedrooms with four modes of window use were investigated. Figure 3 illustrates the results of external airflow rate (Q) and heat balance due to external air (H) in South- and East-facing bedroom on the summer and winter day. It should be noted that the external airflow rate includes incoming air through the operable window due to wind and stack effect during window use, assumed air infiltration when a/c was off and assumed mechanical ventilation when a/c was on.

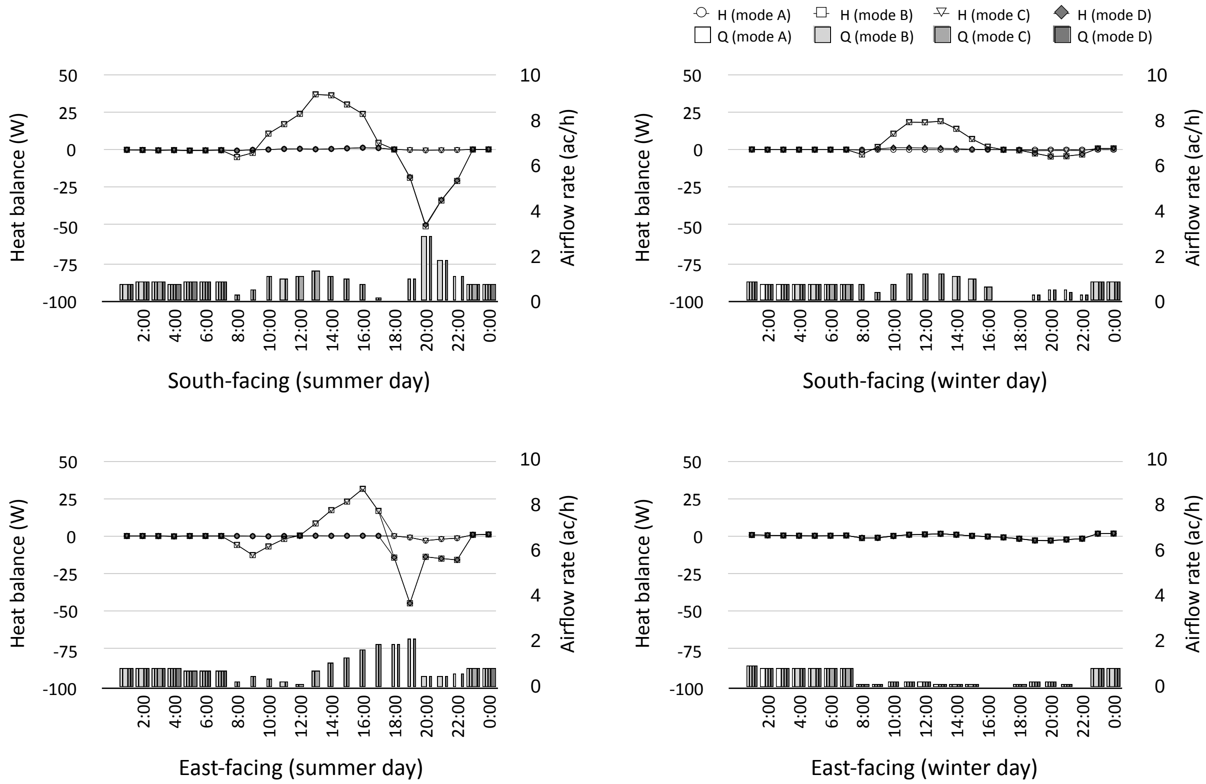

Figure 3: Airflow rate (Q) and heat balance due to external air (H) of South- and East-facing bedroom.

It was found that external airflow rate in all cases was relatively small as the studied bedroom was single-sided ventilated. According to the average wind speed on the summer and winter day of 2.1ms^{-1} and the prevailing wind direction from the North-East, average Q during 8:00-22:00hrs (a/c was off) for South- and East-facing bedrooms were 0.4-1.0 ac/h on the summer day and 0.2-0.7 on the winter day, depending on modes of window use. This was except for '*no ventilation*' cases where average Q due to external air infiltration was found at 0-0.2 ac/h.

The charts in Figure 3 also illustrate that the incoming air has an impact on the bedroom heat balance. This impact depends on airflow rate and the temperature difference between T_{out} and T_a. Greater volume of airflow rate would have a greater impact on the bedroom heat balance, either to increase or decrease it. During the time when T_{out} was greater than T_a such as during 9:00-17:00hrs in South-facing bedroom on the summer day, the incoming air created the heat flow into the bedroom and caused the room T_a to rise (see also T_a of the bedroom with '*day-time ventilation*' on Figure 2). The inverse results were found in the morning and in the evening, for instance, during 8:00-9:00hrs and 18:00-22:00hrs for South-facing bedroom; and during 8:00-11:00hrs and 18:00-22:00hrs for East-facing bedroom. Window use during early morning and, especially, in the evening are therefore preferable for reducing the bedroom T_a and cooling load.

Effect of window uses on bedroom cooling energy

The effect of window uses on the bedroom cooling energy was investigated. Figure 4 illustrates the results of annual cooling energy use of the four-oriented bedrooms with different window uses.

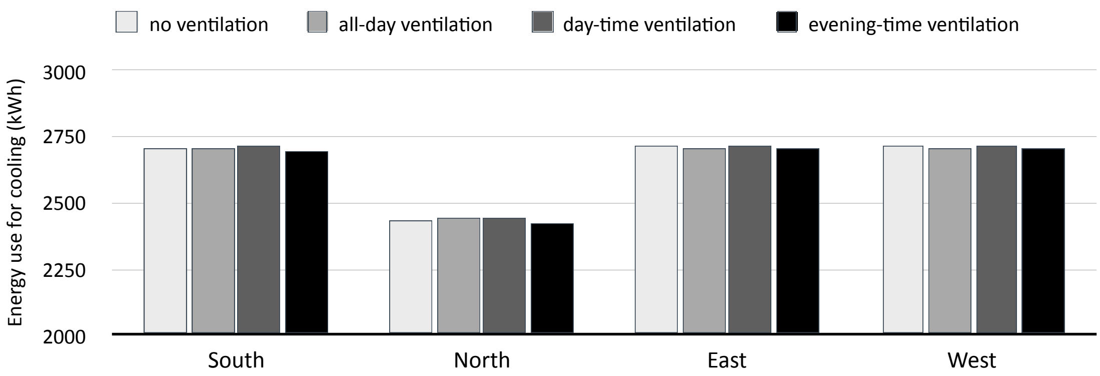

Figure 4: Annual energy use for cooling of the bedrooms with four window uses.

The bedroom cooling energy was found depending on the room's orientation. North-facing bedrooms were found to have the lowest cooling energy for all modes of window use, while other bedrooms had fairly similar results. Different window uses were found to have a slight effect on the bedroom cooling energy. Except for the East-facing, the bedrooms with '*evening-time ventilation'* were found to have the lowest annual cooling energy, followed either by "*all-day ventilation*" for South- and West-facing bedrooms or "*no ventilation*" for North-facing bedroom and the bedrooms with "*day ventilation*" were found to have the highest cooling energy. This was because T_{out} in the evening was relatively lower than the bedrooms' T_a, so the incoming air helped reducing the rooms' T_a and sensible cooling load. On the contrary, the incoming air during daytime, which has relatively higher temperature, increased the bedroom T_a and therefore the room sensible cooling load. The cooling energy difference between the bedrooms with '*evening-time ventilation'* and '*day ventilation'* were found as 13.0-17.6kWh per year, depending on the room's orientation.

For East-facing bedrooms, the bedrooms with '*all-day ventilation'* were found to have the lowest cooling energy, while the bedrooms with "*no ventilation*" had the highest. This was because the bedrooms' T_a rose quickly since the early morning and became greater than T_{out} since then. Therefore, it was not only the incoming air during the evening, but also during the morning (8:00-11:00hrs) could help reducing the East-facing bedroom's T_a and cooling load.

Conclusion

In this study, typical characteristics of high-rise condominiums in Bangkok metropolitan area and the resident behavior were surveyed. It was found that all of the condominiums are the change-over type of mixed-mode buildings. Natural ventilation and a/c are both employed in the same area, but at different time. Most of the residents operated a/c in their bedrooms during the night, regardless of the external climatic conditions. Employing natural ventilation in such case is therefore a challenging issue. Four different modes of window use found from the survey: '*no ventilation*', '*all-day ventilation*', '*day-time ventilation'* and *'evening-time ventilation*' were simulated in this study aiming to discover its effect on the bedroom's cooling energy.

The bedroom's air temperature and cooling energy are found depending greatly on the room's orientation regarding to the sun path. Window use also has an effect on the room's cooling energy. In most cases, the bedroom with *'evening-time ventilation*' has the lowest annual cooling energy, while the room with '*day-time ventilation'* had the highest. This impact of window use depend on external airflow rate and temperature difference between indoor and outdoor air temperature. Greater volume of incoming air would provide a greater effect on increasing or decreasing the bedroom's cooling energy. Window use during the time when outdoor air temperature is relatively lower than indoor air temperature, such as during the early morning and in the evening, is preferable for reducing the room's cooling energy use and could be adapted as a promising post-occupancy strategy to help a mixed-mode building to achieve more energy efficiency. However, the results of airflow rate in this study were very small due to the fact that the studied bedroom was single-sided ventilated. Opening design that allows a greater incoming airflow rate would produce the greater effect of window use on the bedroom's cooling energy use reduction. This issue would be the near future study.

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A Comparative Study for the Selection of a Curtain Wall Glazing type Suitable in a Regional Hot Arid Climate Condition

Khaled Tarabieh[1], Islam Mashaly[1] and Yussra Rashed[2]

[1] Building Sciences Lab, Department of Architecture, School of Sciences and Engineering, American University in Cairo, New Cairo, Egypt, ktarabieh@aucegypt.edu

[2] Department of Structural Engineering, Ain Shams University, Cairo, Egypt, yussra.mer@eng.asu.esu.eg

Abstract: The study is focused on the performance evaluation of three types of glazing typically available in the market through the utilization of an office building as a case study located in a hot arid climate zone. The aim of the paper is to enable designers to select the most suitable glazing type through a comparison between different options of available commercial glazing types and study the payback analysis and financial return using market costs. Whereas various climatic regions were taken into consideration in three MENA countries. The baseline used for benchmarking is a clear glazing type compared against the three studied glazing types. Results showes that the SHGC value is the key factor that affects the energy consumption, especially the window solar gain. Another factor that was taken into consideration is the U-value; however, there is a certain threshold for the U-value where its reduction becomes inefficient. A model was developed and tested in several climates to determine whether the threshold would vary from one location to the other. Furthermore, the selection of the most suitable glazing is ultimately a compromise between the economic performance and energy conservation.

Keywords: U-value, curtain wall glazing system, hot (arid/dry) climate, payback analysis, energy Analysis

Introduction

Glazing technologies have advanced in a competitive way that reformed the way choice decisions are made. Decisions are not made through only picking the best properties or the best cost, but a combination of measures and optimized performances are taken to ensure a balanced sustainable choice in terms of economic, environmental and social benefits. Solar heat gain coefficient and the U-value are two of the main properties of a glazing panel that affect its thermal performance. Since glazing is considered one of the most influential performance meters in the building envelope, the slightest change in their values would induce a great change in energy consumption in the building. A variety of glazing materials are used to balance between the amount of light transmitted inside, and amount of heat prevented. Low-E, for example, are spectrally selective coatings applied on the glass panel, which reflects infra-red radiation without any significant loss of visible light transmission. Electro-chromatic material is another application, where it is able to adjust the optical properties of the glass through running voltage. (Granqvist, 1995) (Papaefthimiou, Leftheriotis, & Yianoulis, 2001)

Moreover, decreasing the U-value of the fenestration system is an effective way for energy. One way of doing so is through adding more than one layer of glazing and applying gaseous material in between. Different glazing systems were tested and analyzed in a residential building in California by Sullivan et.al. The single, double and triple-glazed windows were observed against their energy efficiency in different climatic conditions (Sullivan & Selkowitz, 1985). While Rousseau concluded that higher thermal resistance can be observed having a layer of inert gas results in when than single glass panes, which determines that gaseous layers have more thermal impact on the overall U-value than the glass itself (Rousseau, 1988). (Kim, 2011) used a comparative life cycle assessment approach to compare a transparent composite façade system (TCFS) and glass curtain wall system (GCWS). In the assessment he compared both alternatives throughout all stages of their life cycle from an environmental aspect; considering both the energy consumption and the CO_2 emissions. The main recommendations were to carry out further research for different climatic zones, building types and orientations. In addition, it was pointed out that the results could change upon utilizing a dynamic SHGC instead of a single SHGC, therefore its effect should be tested as well.

Methodology

The aim of this paper is to compare the performances of four glazing types (Note: for the academic purpose of this paper, the actual brand names of the four types were renamed to clear, Type T, Type S and Type G). Different weather conditions for three regional locations were chosen: Cairo, Egypt (hot desert climate); Dubai, United Arab Emirates (tropical desert climate), and Algiers, Algeria (temperate zone) as shown in Figure 1.

Figure 1: The three locations selected with different climate conditions

The objective of the paper to serve as a comparative analysis case study with a main purpose to give an insight of how the glazing type chosen will affect the Energy Use Intensity (EUI) in different climatic zones and how the cost of the different glazing would affect the payback period. However, the analysis performed have been based upon simulation tools results, therefore the values given are only accurate if all variable match those of the simulation inputs. For the purpose of glazing selection, the comparative analysis is indeed a useful decision making tool. In the comparison process all the variable and inputs are kept constant for all alternatives, only the glazing specifications are changed. For the analysis to correctly demonstrate the impact of the glazing type key variables were defined based on the client's input data. These variables include, but are not limited to, the building's location, architectural model, and orientation. Nonetheless, the glazing technical specifications like the

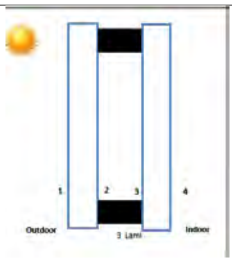
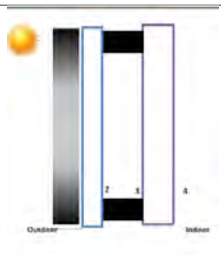
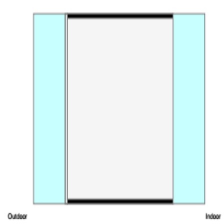
U-value and the Solar Heat Gain Coefficient [SHGC] were fundamental inputs for the simulation process. Performing such a comparative analysis required the following work phases:

1. *Modeling* the architectural model with all the details as well as setting the building orientation and location.
2. *Defining* the glazing properties for the clear glass
3. *Performing* an energy simulation analysis and extracting the energy performance data
4. *Altering* the glazing properties to match the other types glass instead of the clear
5. *Obtaining* the energy performance data for the other glazing types and different locations scenarios
6. *Comparing* the energy performances for all scenarios and calculating the energy savings
7. *Calculating* the savings in terms of the price of energy consumption and performing a payback analysis

Glazing Types

The properties of all glazing alternatives are given Table 1 below:

Table 1: Properties of the Alternatives

	Clear	Type-S	Type-T	Type-G
Cross Section				
Specification	6mm Clear/16mm A.S/6mm Clear	6mm Tinted Gray+1.14mm PVB+ 4mm clear/20mm A.S/6mm SG 500 low E	6mm Tinted Gray/16mm A.S/6mm Clear	6mm PLANILUX+ COOL-LITE KNT 155/20mmA.S/6mm PLANILUX
U-Value	2.7	1.7 (Air) / 1.5 (Argon)	2.7	1.7
SHGC	0.74	0.37	0.44	0.43
Cost ($/m²)	33.7	69.8	40.5	67.6

Overview of building location and simulation engine

Office building located in New Cairo, Egypt with a north east orientation (angle to north = 36^o).

Figure 2: The location and architectural rendering of the building case study

The choice of the simulation tool was based upon two main criteria; the first is the simulation engine capabilities as well as a flexibility in altering the glazing properties, the second is the modelling complexity. Having an architectural model with elevations mainly of curtain walls and the fact that the glazing is the main element of this analysis, maintaining the model details was extremely crucial. The program used for both modelling and energy simulation is Autodesk Revit®. The energy simulation was carried out using the cloud based energy analysis tool powered by Autodesk Green Studio Energy Analysis, the engine used is DOE 2.2.

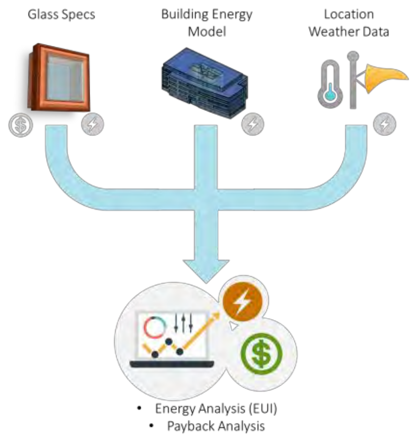


Figure 3: The simulation inputs and outputs

The inputs of the energy simulation were as follows:

- The building model including the main architectural details, and with the actual orientation.
- The glazing specifications as previously mentioned
- The accurate location and the corresponding weather data

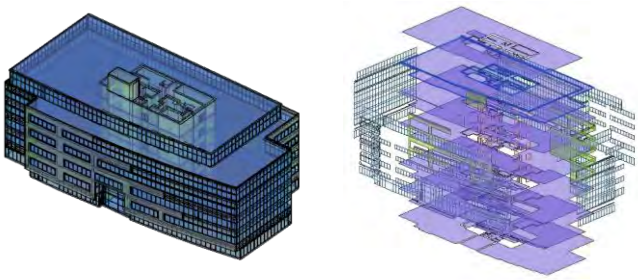


Figure 4: The analytical energy model (left) and the breakdown of the analytical surfaces (right)

For the purpose of creating a comparison between the performances of the four glazing types, four energy simulations were carried out in each of the selected regions. The glazing specifications were altered for the analysis but every other aspect was kept constant. The outputs of interest to this energy analysis are the Energy Use Intensity of the building in kWh/m^2/year and the window solar heat gain in kWh and the space cooling loads in kWh. These outputs were obtained for all the glazing types, hence computing the differences was possible.

Results Overview

The energy simulation results comparison showed that replacing the clear glass with any of the other types that has a lower U-value or a lower SHGC can indeed decrease the EUI, cooling loads, and window solar heat gains. The decrease in the SHGC had a greater impact on the EUI than the decrease in the U-value. However, the reduction percentage of the EUI is associated with the climate area. The improvement in EUI for Dubai scored the highest reductions ranging between 10.6% for Type-S and 8.4% for Type-T, while Algeria scored the lowest improvements of 7.9% only for the Type-S and 6.0% for Type-T. In all climatic zones, Type-S, which has the lowest U-value and lowest SHGC, proved to be the best energy saving while Type-T glass showed the lowest improvements in energy intensity. The differences between all the scenarios is shown in Figure 5 and the percentages in EUI improvement are illustrated in Figure 6.

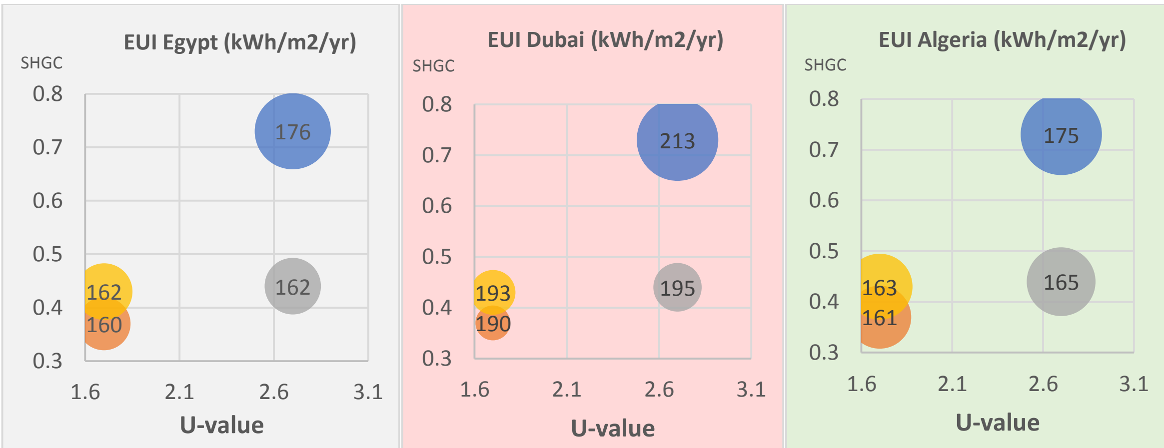


Figure 5: Energy Use Intensity (SHGC as a function of U-value)

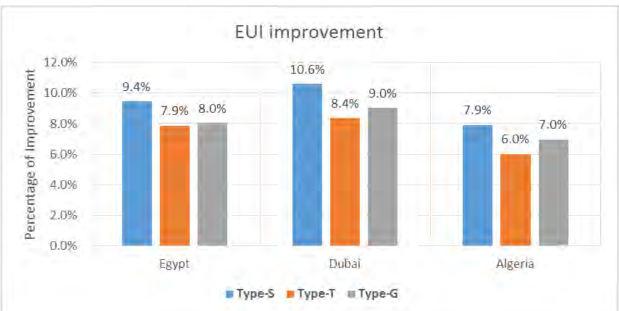


Figure 6: Energy Use Intensity improvement

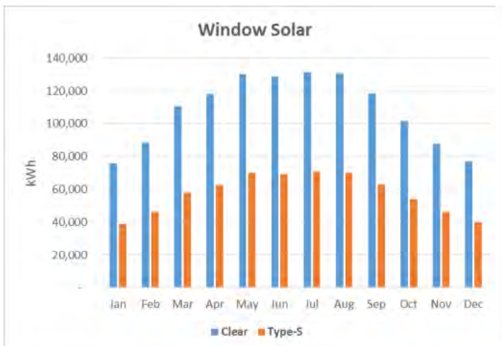


Figure 7: Window Solar Heat Gain per Unit Area

Window Solar Heat Gain, Electricity and HVAC loads savings

Figure 4 above clarifies the impact of using lower SHGC and lower U-value glazing type as the window solar heat gain values have been dramatically reduced. Nonetheless, decreasing the window solar heat gain loads lead to a reduction in the cooling loads and in the HVAC electricity usage. In a hot arid climate like Cairo and Dubai, this reduction in HVAC loads is of great importance and represents a large value of energy savings. The difference in electricity savings is certainly more drastic in summer months reaching up to 12% savings in months like August, September and October, as shown in Figure 8, due to the savings in the HVAC cooling loads. However, for Dubai, the electricity savings has no regular pattern, since the weather in Dubai tends to be warmer all year. As for Algeria, the electricity savings are slightly lower than Dubai and Cairo around the year except for July and August where the savings reached 12%. As for the HVAC savings in all three locations for the three glazing types, Type-S proves to have the highest saving percentage of 22.36%, as shown in Figure 9.

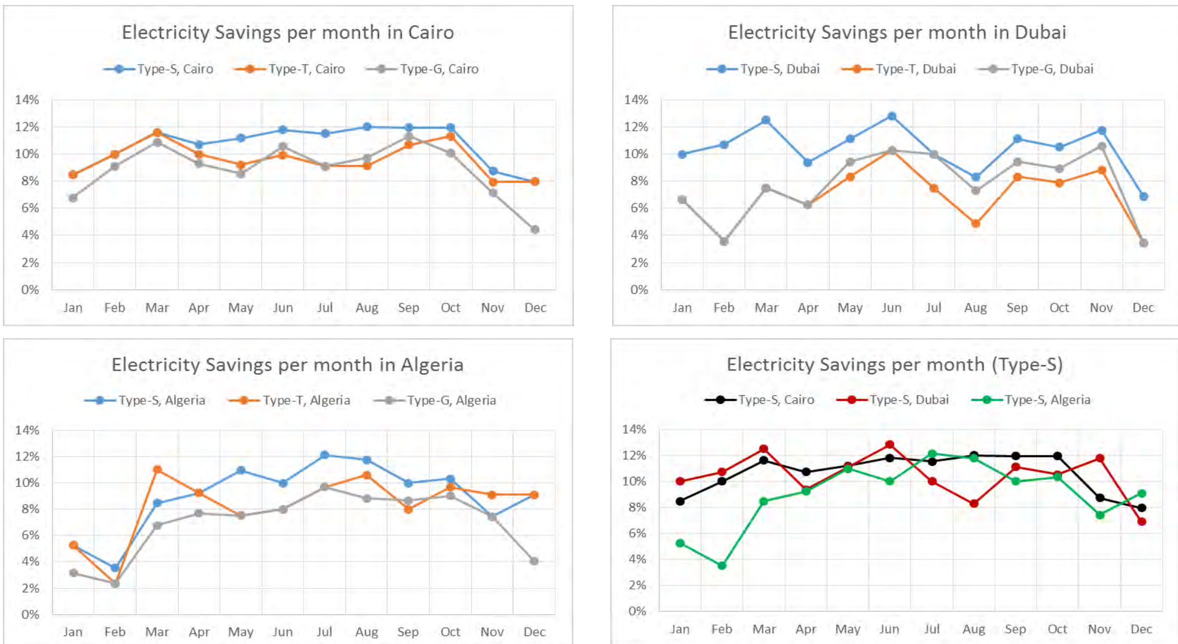


Figure 8: Electricity Savings per Month for Cairo, Dubai and Algeria, and for Type-S per country

On the other hand, the HVAC savings in Dubai was lower than the expected pattern although the impact on the total EUI was higher than other regions, where Dubai's Type-S glazing showed lower improvement than Cairo and Algeria with a value of 17.89% only. This means that the higher temperature would not always result in higher savings. On another note, the savings from the tinted glazing were higher than Type-G in both Cairo and Algeria, however, in Dubai, Type-G would be a better option than the Type-T.

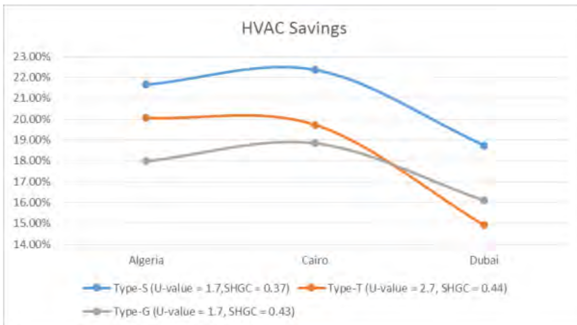


Figure 9: Savings percentages in the HVAC loads

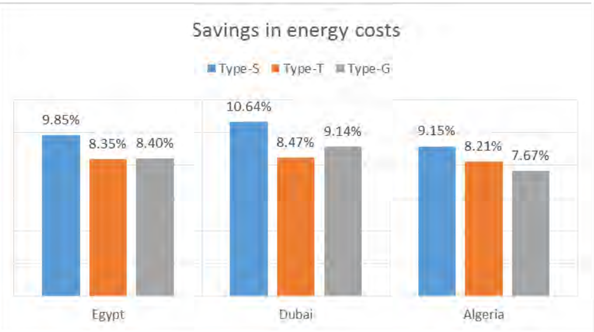


Figure 10: Savings in Energy Costs

Cost analysis

The cost analysis shown in Table 2 was based on the following assumptions list for the electricity and fuel rates for all three regions and an interest rate of 6.1%.

Table 2 List of assumptions for the cost analysis

Parameter	Egypt	Dubai	Algeria
Electricity Rate ($/kWh)	0.05	0.10	0.03
Natural Gas Rate ($/kWh)	0.034	0.05	0.0055
Glass Built Area		3508 m^2	
Interest rate		6.1%	

Cost savings & Payback analysis

The energy savings, in terms of cost (Figure 10), achieved with Type-S is the highest among the three locations, saving in the yearly energy running costs for the given building. Noting that the price of energy has been assumed as noted in Table 2 (Tariffs, 2016) (Slab Tarrif, 2016). The investment results for Cairo, Egypt are shown in Figure 11, the payback period is about 7.06 years for Type-S, 14.20 years for Type-G and 3.10 years for Type-T glass. It can be concluded that both the Type-S and Type-T glass are cost effective alternatives as their life-time is at least 10 years, this means the differences in their costs will in fact be paid back in terms of energy costs savings.

The Type-G payback period exceeds its estimated 10 years life-time by 4.20 years, although it has better energy savings than Type-T glazing, which means this alternative is not applicable Cairo. However, in Dubai all three alternatives' payback period are within the 10-years range as shown in Figure 12. In fact, all three alternatives have lower payback periods than in Cairo with 1.26 years for Type-T glass option, 2.71 years for the Type-S, and 5.40 years for Type-G. As for Algeria, only Type-T glass is within the 10-years range with 5.66 years while Type-S and Type-G options are economically inapplicable.

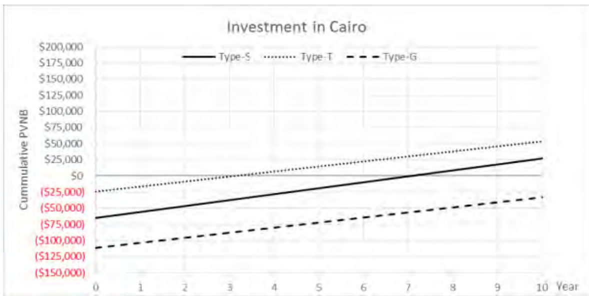


Figure 11: Payback Analysis for Type-S, Type-G and Type-T Glass in Cairo

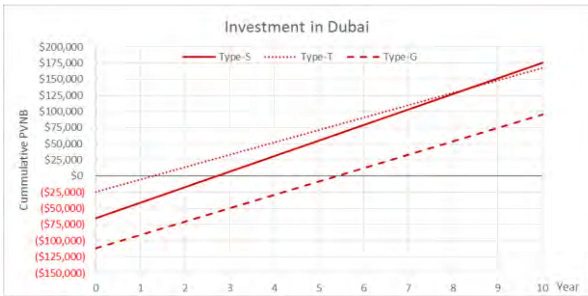


Figure 12 Payback Analysis for Type-S, Type-G and Type-T Glass in Dubai

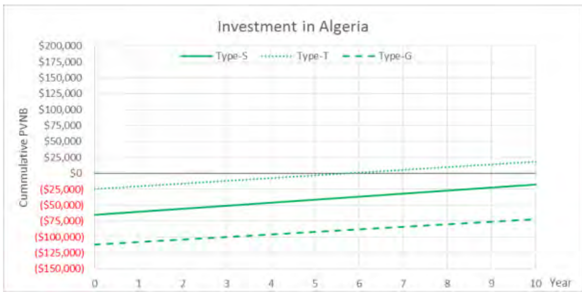


Figure 13 Payback Analysis for Type-S, Type-G and Type-T glass in Algeria

Conclusion

There are two aspects in which the selection criteria can be based upon: Economical effectiveness and Energy-efficiency. From the energy efficiency point of view Type-S displayed the highest records of energy savings in all regions. Although it is economically effective in countries with higher fuel costs, as the payback period for both is less than their life time in Dubai and Cairo, Type-T glass is the most economically effective choice for it recorded the lowest payback period in all three regions and it is highly recommended in Algeria. Both the SHGC and the U-value affect the energy efficiency of the building; however, the SHGC was a more effective factor in saving energy compared to the U-value.

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Thermal comfort based window glass selection for office buildings

Jyh-Tyng Yau[1], Ruey-Lung Hwang[2] and Kuo-Tsang Huang[3]

[1] Architecture and Building Research Institute, Ministry of the Interior, Taipei, Taiwan, jyhtyng@abri.gov.tw;
[2] Department of Industrial Technology Education, National Kaohsiung Normal University, Kaohsiung, Taiwan, rueylung@nknu.edu.tw;
[3] Department of Bioenvironmental System Engineering, National Taiwan University, Taipei, Taiwan, huangkt@ntu.edu.tw;

Abstract: Window is an important part of the building envelope. Although the presence of large window surfaces could be preferable for daylighting and sightseeing. However, more attention has to be paid to limit the transmittance of solar radiation which causes the increase of cooling load during the cooling season. Energy consumption caused by window accounts for a large proportion in the whole building cooling energy consumption. However, the choice of glazing type and the design of windows on a façade may depend on comfort consideration as well as their energy performances. In other words, an energy-saving window glass have to be able to simultaneously take into account the indoor visual and thermal comfort, as well as the energy consumption from lighting system and air conditioning system. Since this field of knowledge lacks experimental quantitative analysis, the purposes of this study are to explore the quantify the effectiveness of the related parameters for the selection of a suitable window glass in perspectives of indoor thermal comfort and energy use. A full-scale experiment was conducted in six experimental chambers against six different types of glass for studying their influences of indoor thermal comfort and the cooling energy use

Keywords: Window glass; Thermal comfort; Energy use

Introduction

Window enables visual access to outdoor scenery and is one of crucial building envelope component. It is capable of providing natural lighting and, from the results of many existing studies, could increase occupants' working efficiency. However, the fenestration is the most vulnerable part regarding its thermal resistance as opposed to opaque walls or roofs. Air-conditioning cooling loads that are gained from solar radiation via windows in summer comprise a considerable proportion of total cooling loads in hot-and-humid regions, such as Taiwan. The excessive heat gain through the windows would not only increase the cooling energy but also would deteriorate the indoor thermal comfort. The fundamental performance parameters of glass related to lighting, thermal environment and cooling energy are: (1) coefficient of conductivity (U-value), which evaluates conductive heat gains by indoor-outdoor surface temperature difference; (2) shading coefficient (SC) or solar heat gain coefficient(SHGC), which for instance of SC, is the ratio of solar radiation heat gain in comparison of a 3mm clear plane glass. The SC value is characterized by 0~1, the larger the number the more solar radiation is gained indoors, and vice versa; and (3) visibility transmittance(VT), which denotes the proportion of transmittance of the visible light. Larger VT suggests there are more visible lights coming inside resulting better natural daylighting. By means of adequate architectural daylighting design, it could reduce the artificial lighting energy and decrease its heat gain. The range of VT would widely vary with the types of glass, number of glass layers and the glass coatings.

This study firstly reviewed the research progress regarding the influence of glass's performance on indoor thermal comfort and cooling energy use. Furthermore, a set of long-term experiments were conducted with six full-scale experimental chambers each installed with different types of glass, including double low energy glass, double reflective glass, double tinted glass, single electrochromic glass, single tinted glass and single clear glass. The objective of this research is to investigate the influences of thermal and optical factors of glass on the performances of indoor thermal environment and cooling energy of buildings.

Methodology

Energy efficient glass and window heat conduction

Currently there are no specific definition of energy efficient glass and physical evaluation index of it in Taiwan. Energy efficient glass is a relative term by comparing its performance to general clear plane glass. The heat flow of a glass pane comprises temperature driven heat conductance and solar radiation heat gain. The fundamental handbook of American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) gave the equational relation of window heat gain as Eq.1. The first term of the equation denotes surface-temperature driven heat conduction, which is calculated by the U-value (U) of glass multiplied by the temperature difference of exterior surface (Tout) and interior surface (Tout); and the second term is for calculating solar radiation heat gains, which is given by multiplying glass's SHGC with solar insolation. It indicates U-value and SHGC are major factors that influence the heat gain from windows. Therefore, National Fenestration Rating Council (NFRC) of the United States adopts U-value and SHGC as crucial factors of glass for thermal performance evaluation purpose.

$$q = U \times (T_{out} - T_{in}) + SHGC \times G \tag{1}$$

Thermal comfort and the fenestration

According to ISO7730 (ISO, 2005), PMV-PPD model has been widely adopted for evaluating indoor thermal comfort. The primary factors that are related to the thermal comfort are ambient temperature, mean radiant temperature, relative humidity and air velocity based on the PMV-PPD model. Lyons et al. (Lyons, Arasteh et al. 2000) emphasized that to quantify the effect of the window glass on occupants' thermal comfort, two additional factors, direct and diffuse solar radiation, should be considered except for the longwave radiation from the surrounding surfaces. Arens et al. (Arens, Gonzalez et al., 1986) and Sullivan (Sullivan, 1986) linearly estimated the PPD in the presence of direct solar radiation, as depicted in Figure 1. The solar-adjusted PPD was calculated from the net PMV obtained from the summation of the thermal comfort tool calculated PMV under no solar presence circumstance and that of the solar-adjusted PMV. Once the non-solar-existed and solar-existed PPD are known, the value of PPD under the sole influence of the sun, which is ΔPPDsolar, can be obtained by simple arithmetic deduction. Namely, the net PMV is the sum of the non-solar-existed PMV and the solar-adjusted PMV. The ΔPPDsolar can be derived from deducting the total PPD (PPDtotal) by the surface-influenced PPD (PPDsurface), and is given by:

$$PPD_{total} = PPD_{surface} + \Delta PPD_{solar} \tag{2}$$

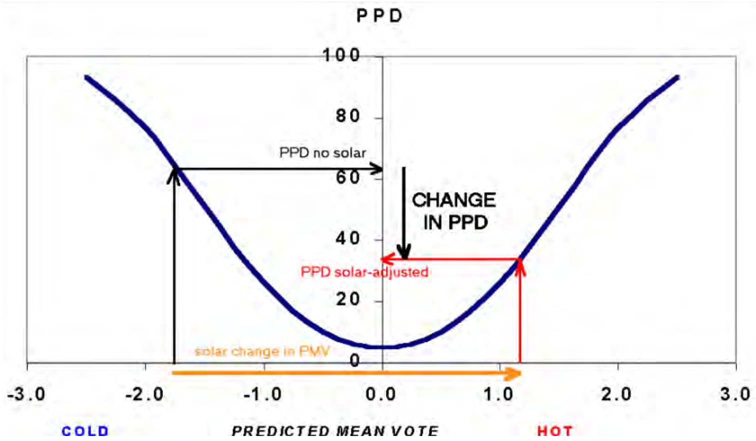


Figure 1 Concept of Solar Adjusted PPD-PMV

The Full Scale Experiment

To understand the thermal comfort variation due to the aforementioned theory and the cooling energy efficiency of various fenestration glass, six full-scale experimental chambers each installed with a variable-speed split-type air conditioner were constructed located at southern Taiwan, as show in Figure 2. Each experimental chamber was remodeled from a standard 20ft shipping container (6.09 m in length, 2.44 m in width and 2.59 m in height) with the interior floor area being 14.4m2. The six experimental chambers were identical in their geometries, thermal resistances of exterior opaque walls, interior configurations, air-tightness of the fenestration. The experimental fenestration surfaces were all at the west side façade of the chamber and each were made of two panes of 1.0 m by 2.0 m glass with a fenestration area of 4 m2. The types of glass for experiment and their thermal properties are listed in Table 1, the U-values range from 2.5 to 5.6 W/m2K and the values of SHGC range from 0.28 to 0.85. The 8 mm single clear glass is regarded as a reference as this is the most commonly seen glass used in Taiwan.

The monitored parameters, including the electricity usage of the air conditioner, indoor air temperature, relative humidity, globe temperature as well as air velocity were recorded by sensors or instruments listed in Table 2. The air-conditioners' electricity consumptions were recorded by digital electricity meters. The thermal comfort measurement was conducted by two sets of thermal environmental monitoring system, one was placed at 1.5 m away from the fenestration and the other was placed 4.5 m away from the fenestration, each for measuring the solar affected and the non-solar affected thermal conditions. The measurement was recorded with a frequency of 2 minutes and sampling at 2 Hz for each sensor

Figure 2: Full-Scale Experimental Platforms for Building Energy Research.

Table 1: Thermal Properties of the Experimented Glass

Exp. no.	Layers of glass	U-value ($W/m^2.K$)	SHGC
1	8mm single clear glass	5.6	0.85
2	8mm single tinted glass	5.6	0.52
3	8mm single electrochromic glass	5.2	0.38
4	8mm tinted+8 mm air gap+8 mm clear glass	3.0	0.35
5	8mm reflective+8 mm air gap+8 mm clear glass	3.0	0.33
6	8mm low-e+8 mm air gap+8 mm clear glass	2.5	0.28

Table 2: Instruments for Measuring Thermal Environment.

Parameters	Instruments	Model	Resolution
Temperature and humidity	Temp/RH meter	CENTER 314	Humidity:±25 % Temperature:±0.7°C
Globe temperature	Standard copper globe	--	±0.7°C
Air velocity	Anemometer	Delta HD2103.2	±0.01m/s
Luminance	Lux meter	HOBO HE140	±3%

Results and discussion

The experiment was performed during 24th May to 6th June, 2016. The maximum daily outdoor air temperatures during the experimental period were all above 33.0C with the average temperatures being 30.0°C except for days of 24th May and 2nd June. The daily averaged relative humidity was 70%-90%. The PMV calculated by the measured hourly dry-bulb temperature, globe temperature and air velocity was presented in Figure 3. We observed that the case of 8mm single clear glass exhibited the highest discomfort against all cases; and the case of electrochromic glass and the double tinted glass exhibited a relatively low potential of indoor overheating.

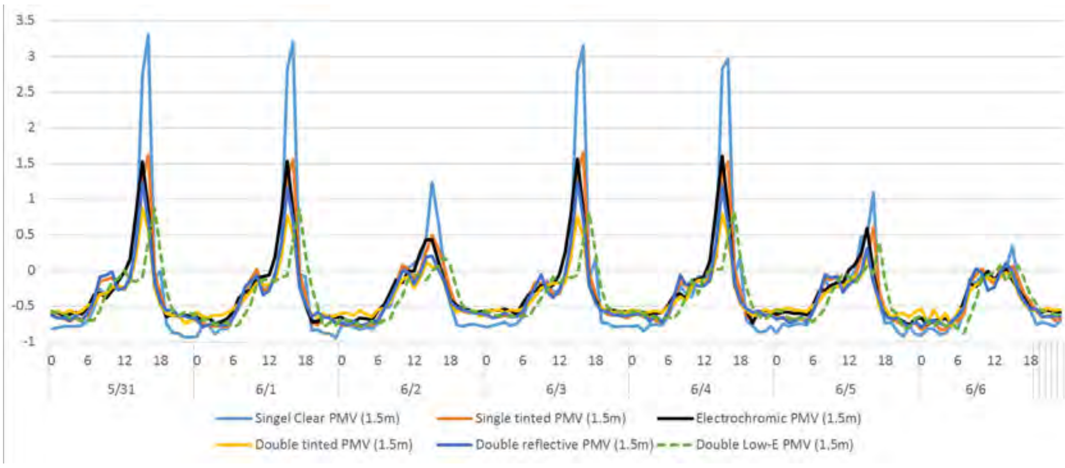
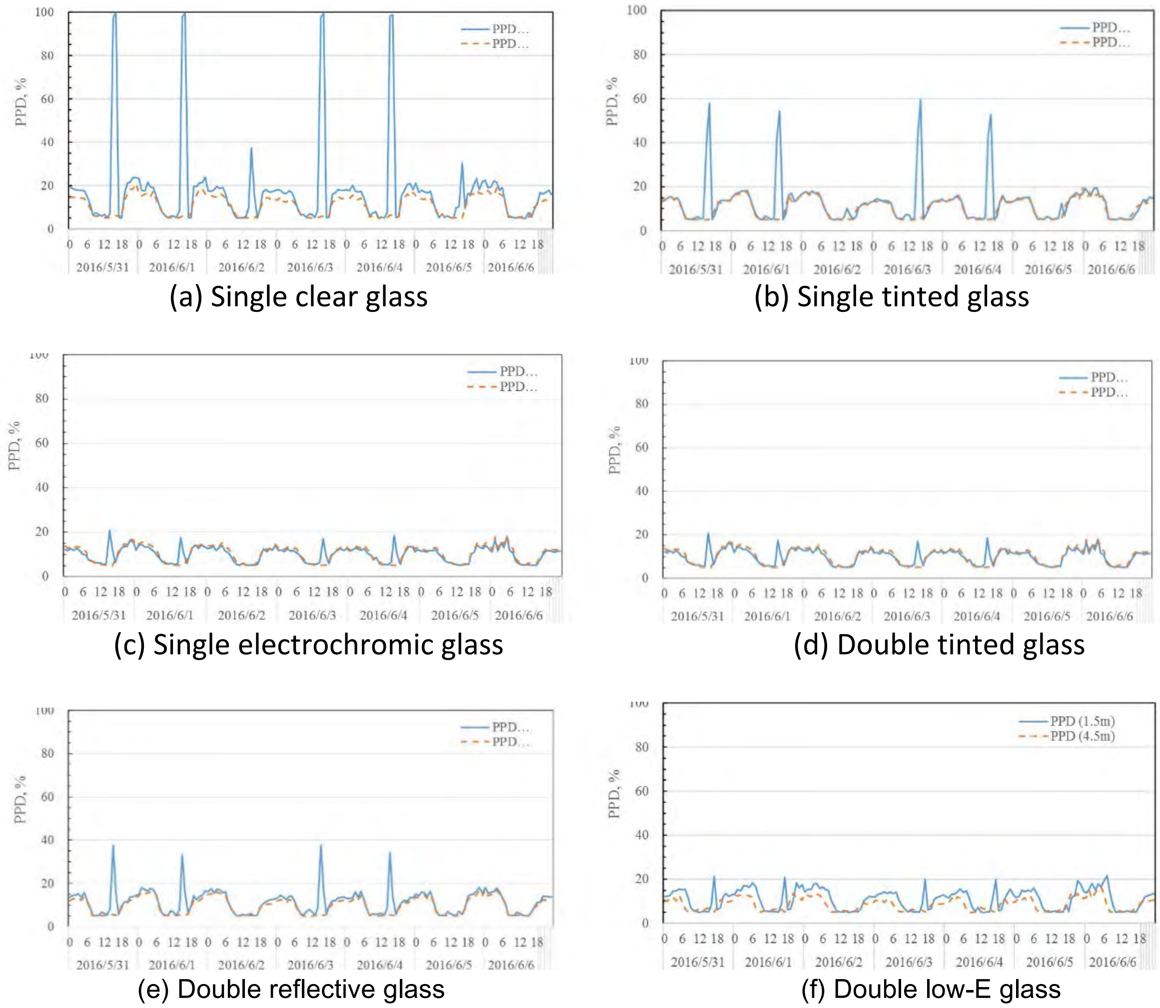


Figure 3: Comparisons of The Calculated PMV 1.5m Away from the Fenestration

The PPD of single clear glass ranged from circa 5%-20%. However, the PPD near to the fenestration was 95% in the everyday afternoon when the direct solar radiation stroke in during the experiment, as shown in Figure 4(a), suggesting a higher thermal discomfort potential at noon. The PPD range of single tinted glass was also mostly around 5%-20% with the highest value of slightly over 50% at noon, as illustrated in Figure 4(b). The daily temporal PPD variations of electrochromic glass, double tinted glass, double reflective glass, double low-E glass were diagramed in Figure 4(c) to Figure 4(f), respectively. In general, the indoor thermal comfort of windows with double glass glazing performed better than single glass.



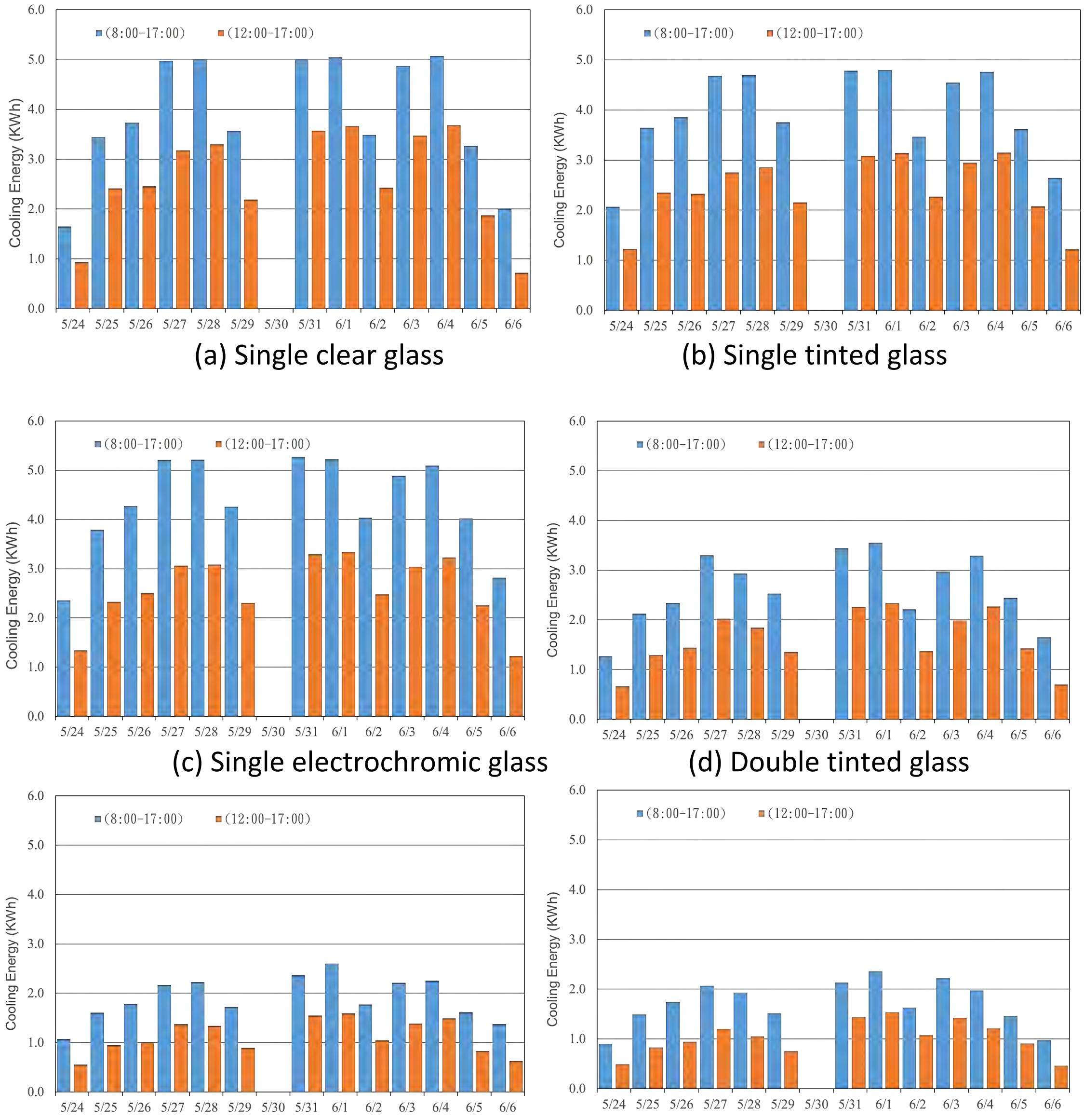
(a) Single clear glass (b) Single tinted glass

(c) Single electrochromic glass (d) Double tinted glass

(e) Double reflective glass (f) Double low-E glass

Figure 4: Daily Indoor PPD Variations of Various Types of Glass.

During the period of experiment, the air-conditioning was kept operating, hence, the daily cooling energy of each case can be obtained by accumulating the hourly electricity meters of air-conditioners in a daily manner. Figure 5 depicted the daily cooling electricity consumptions of all six cases. Since the windows of the experimental chambers are all facing west, the cooling energy uses in the afternoon (12:00-17:00) were also illustrated for comparison. In general double layered glass had lower cooling energy than single layered glass. We discovered that the cases of low-E glass and double reflective glass consumed less cooling energy than the others, followed by the case of double tinted glass. Interestingly, the single tinted glass outperformed the electrochromic glass in term of energy efficiency.



(a) Single clear glass (b) Single tinted glass

(c) Single electrochromic glass (d) Double tinted glass

(e) Double reflective glass (f) Double low-E glass

Figure 5: Daily Cooling Electricity Consumptions of the Six Cases.

Conclusion

The proper selection of fenestration glass has a significant impact on the indoor occupants' thermal comfort as well as cooling energy use. The thermal properties of thermal resistance and shading coefficient of a glass should be both synthetically considered during building fenestration design. Moreover, the selection of glass should also consider local climate to meet energy conservation needs and also fulfill the demand of occupants' thermal comfort. In this study, we investigated the thermal comfort and the energy performances of six common seen fenestration glass by conducting experiments in full-scale experimental chambers in a climate context of hot-and-humid. The results revealed that double layered glass with a lower SHGC would have better performances in indoor thermal comfort as well as cooling energy consumption.

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